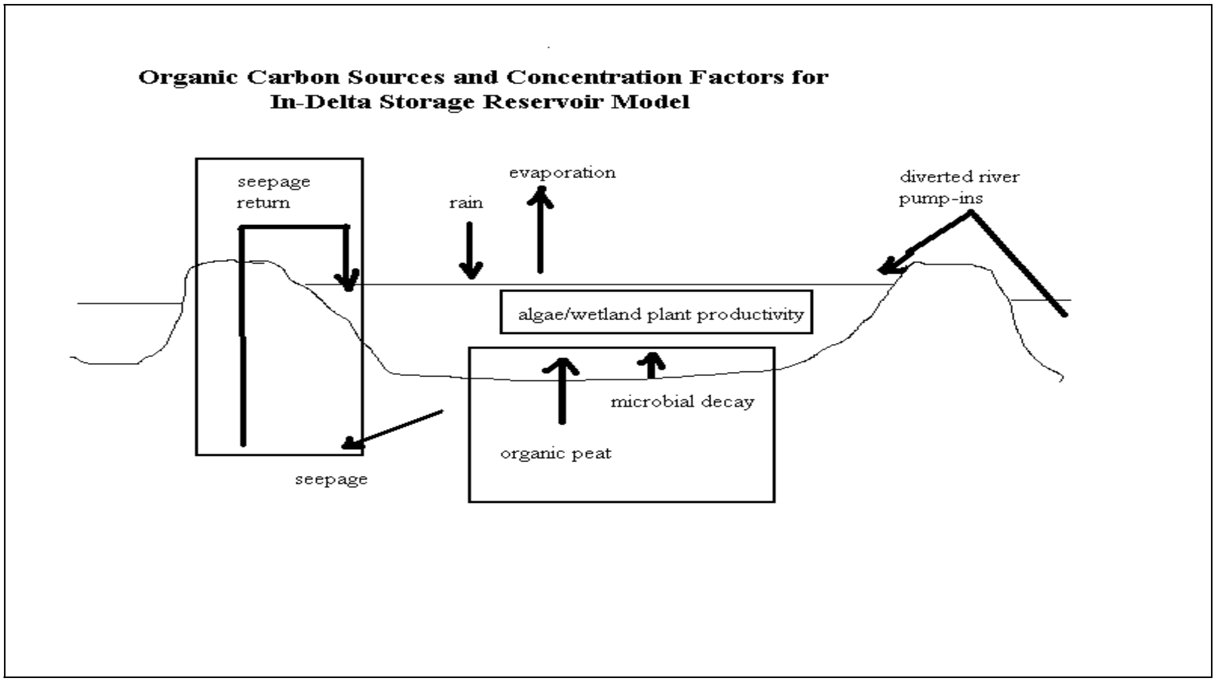
FINAL REPORT OF:3/6/02 11:33 AM
File: Final CR4 WQ Model for ISI.doc

Synthesis of Data for Development of Reservoir Island Organic Carbon Model in DSM2 Model



Technical Report for the Department of Water Resources
Delta Modeling Section

Marvin Jung

MWQI-CR#4

May 2002

Synthesis of Data for Development of Reservoir Island Organic Carbon Model in DSM2 Model

Technical Report for the Department of Water Resources
Delta Modeling Section

Marvin Jung [1/]

MWQI-CR#4

May 2002

This report prepared under DWR contract #4600001162 by Marvin Jung & Associates, Inc., for the Department of Water Resources, Environmental Services Office, Water Quality Assessment Branch, Municipal Water Quality Investigations Program

1/ Marvin Jung & Associates, Inc. 1370 Pebblewood Drive, Sacramento, CA 95833 or
c/o Dept. of Water Resources, P.O. Box 942836, Sacramento, CA 94236-001

Marvin Jung is scientific consultant to the Municipal Water Quality Investigations Program of the Department of Water Resources. He has written over 20 publications on the drinking water quality of the Sacramento-San Joaquin Delta. His work has been the foundation for many studies on the impacts of delta island drainage on municipal water supplies. Mr. Jung created and designed the SMARTS experimental station for DWR. He has served as an advisor, consultant, and expert witness on many San Francisco Bay and Delta water quality studies. His clients have included the State Water Resources Control Board, California Department of Water Resources, U.S. Bureau of Reclamation, State Water Contractors, the Metropolitan Water District of Southern California, and California Urban Water Agencies. He has a B.S. degree in Chemical Oceanography from the University of Washington (1972) and a M.S. degree in Oceanography from the University of Michigan (1973).

Selected Publications

Jung, M. 2000. Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs. Prepared for the CALFED Ad-Hoc Workgroup to simulate historical water quality conditions in the Delta. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#3. December 2000.

Jung, M. and L. Weisser. 1999. A trial experiment on studying short-term water quality changes in flooded peat soil environments. Report for California Urban Water Agencies and Municipal Water Quality Investigations Program of the Department of Water Resources. Marvin Jung & Associates, Inc., Sacramento, CA. July 1999.

Jung, M. and L. Weisser. 2000. Final report on experiment #2: Seasonal water quality changes in flooded peat soil environments due to peat soil, water depth, and water exchange rate. Study conducted and funded by the Municipal Water Quality Investigations Program Division of Planning and Local Assistance California Department of Water Resources. Marvin Jung and Associates, Inc., Sacramento, CA. December 2000.

Jung, M. and Q. Tran. 1998. Delta Island Drainage Volume Estimates, 1954-55 versus 1995-1996. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#1. Marvin Jung & Associates, Inc., Sacramento, CA. January 1998.

Jung, M. and Q. Tran. 1999. Candidate Regions for Treatment to Reduce Organic Carbon Loads. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#2. Marvin Jung & Associates, Inc., Sacramento, CA. January 1999.

Table of Contents

List of Tables

List of Figures

List of Photographs

1. INTRODUCTION

The CALFED Bay-Delta Program's Record of Decision (ROD) identified the proposed Delta Wetlands Project (DWP) as one of the In-Delta Storage (IDS) Program projects to be pursued under Stage 1. The ROD requires feasibility studies to assess the Delta Wetlands Project or other new project should the DWP prove cost prohibitive or infeasible. A selection and recommended project alternative must be made by December 2001.

The proposed Delta Wetlands Project involves the conversion of four Delta islands to wetlands habitat and water storage facilities. Webb Tract and Bacon Island would have water diverted and stored to serve as reservoir islands. Holland Tract and Bouldin Island would become habitat islands and have water seasonally diverted to create and enhance wetlands and to manage wildlife habitat.

One of the major concerns during the State Water Resources Control Board (SWRCB) hearings for granting a water rights permit for the DWP was the potential impact of the Delta Wetlands Project on drinking water quality, especially, total (TOC) and dissolved organic carbon (DOC) concentrations. The water quality of agricultural drain water from the organic-rich peat soil Delta islands are high in organic carbon and salts. Flooding these islands may result in stored water of poor drinking water quality and releases could raise the TOC/DOC at the municipal drinking water intakes in the Delta.

New USEPA regulations under the Stage 1 Disinfectants-Disinfection By-Products Rule (D-DBP) and TOC Removal Rule require enhanced coagulation and flocculation to reduce TOC concentrations prior to disinfection so water treatment plants can meet more stringent Maximum Contaminant Levels (MCL) for disinfectants and disinfection by-products. The rules become effective on January 1, 2002.

Measures to protect the quality of drinking water supplies in the Delta have been outlined and agreed upon between the DWP owners and Contra Costa Water District (CCWD) and the California Urban Water Agencies (CUWA). A Water Quality Management Plan (WQMP) was developed and constraints in the plan have been incorporated into the final decision by the SWRCB that granted the permit application for the Delta Wetlands Project.

As part of the feasibility study, the Municipal Water Quality Investigations Program (MWQI) of the Department of Water Resources (DWR) is assisting in the development of a water quality module for the Delta Simulation Model version 2 (DSM2) to study the operation of the DWP. The purpose of the module is to simulate organic carbon concentrations in the impounded water of In-Delta Storage reservoirs. The model is generic in the sense that it can be applied to other candidate islands and tracts in the Delta besides the DWP islands.

The general scope of work assigned to the MWQI Program consultant and staff included developing a conceptual model and mathematical relationships to describe changes in organic carbon concentrations in the IDS reservoirs based on existing data. Explanatory variables included diversion water quality, storage holding time, season, water level, and soil characteristics. Additional tasks requested by the Integrated Storage Investigations (ISI) Program included developing field and laboratory analyses and experiments to supplement the reconnaissance-level study of the alternatives and to refine the assumptions used in the module.

With this information, the Delta Modeling staff of DWR will develop a water balance module that incorporates the concepts and mathematical relationships that were developed and described in this report and link this module to DSM2. Model development and refinement work will continue through 2001 to adopt the modules in the new CALSIM2 model to simulate water quality changes from the IDS alternatives in meeting the WQMP under different SWP and CVP operational conditions.

This document is a technical report to the Delta Modeling Section. It describes the synthesis of data that led to the development of the algorithm to the reservoir island organic carbon model. It includes historic data on DOC concentrations and related parameters at Delta locations that may serve as source water for the DWP islands and at those sites that may be affected by the island discharges. Data from various shallow wetland studies that were used to predict the DOC on DWP habitat islands are also presented.

2. APPROACH

Specific information were compiled to:

1. Examine the seasonal trends in DOC and related parameters near Delta locations that may serve as the source of diverted water for the DWP islands or be affected by their discharges. DOC and UVA 254nm data are used to validate the DSM2 model.

2. Compare the ranges of DWP island drainage DOC concentrations to assess the relative potential levels of released organic carbon during initial shallow flooding.

3. Develop a conceptual model of the seasonal trends in organic carbon concentrations in flooded peat soil environments, including wetland habitats and water storage impoundments. This information would provide estimates of the expected water quality conditions in the stored water of the reservoir islands during holding and at discharge and in the shallow wetland habitat island discharges.

4. Develop sound assumptions that are supported and quantifiable, and identify data gaps in the conceptual model and mathematical relationships between water quality and other factors. This task was used to develop data collection work, including field and laboratory analyses and experiments, for supplementing and refining the model and evaluating the feasibility of the IDS alternatives.

The primary sources of data included reviews and data analysis of the following:

- Delta channel and drainage water quality data collected since 1986 by DWR.
- Reports of the MWQI Program and predecessor programs since 1982.
- Tank experiments conducted by MWQI in 1998-2000 at the SMARTS facility.
- Wetland water quality experiments conducted by the consultants of the DWP on a Holland Tract demonstration pond in 1989-90.
- A drainage and groundwater quality study conducted by the USGS for MWQI at Twitchell Island in 1996-97.
- Published wetlands studies and data from university scientists.
- Reports and testimonies presented during the Delta Wetlands Project EIR/EIS hearings.

Peer review of the synthesis of data and algorithm developed for the organic carbon model was performed under contract to Professor K. Ramesh Reddy of the University of Florida.

3. RESULTS

The results of the work are presented in the following sections:

- 3.1. Channel water quality near DWP island intake and discharge points
- 3.2. Agricultural drain water quality of DWP islands
- 3.3. Studies of flooded peat soils
- 3.4. Conceptual model for water quality on IDS reservoir islands

3.1. Channel water quality

The sources of water and points of diversion (siphon pumps) for the DWP islands are listed in the Notice of Petitions on Pending Applications 30267 – 30270 (dated April 7, 1995) from the SWRCB. Some diversion points will be located at existing drainage pump stations and there are some new diversion points.

Table 3.1-1. Water Sources of Delta Wetlands Project Islands

Delta Wetlands Project Island and use	Sources of water
Bouldin Island (wetland habitat)	Mokelumne River, Little Potato Slough, Potato Slough, San Joaquin River
Webb Tract (reservoir)	False River, San Joaquin River, Old River
Holland Tract (wetland habitat)	Roosevelt Cut, Holland Cut-Old River, Rock Slough, Sand Mound Slough
Bacon Island (reservoir)	Old River, Middle River, Santa Fe Dredge Cut, Connection Slough

Under the proposed DWP plan of operation and permit application, the season of diversion is January 1 to March 31 and June 1 to December 31 of each year for the two reservoir islands, Webb Tract and Bacon Island.

DOC, UVA-254nm, and specific UV absorbance (SUVA) data from channel stations around the Delta Wetlands Project islands were plotted by month from the MWQI database. The period of record in the MWQI WDL database was 1986 to 2000. Records prior to 1986 were not included due to insufficient QA/QC data. Some stations were sampled during special synoptic sampling runs, others during routine monthly runs. The monthly scatter plots show the range of values seen at these locations. The stations included those that could represent water quality diverted into the reservoirs or those that could be impacted by the DWP releases.

The stations (north to south) are listed below and shown in Figure 3.1-1.

Table 3.1-2. MWQI Channel Stations

MWQI channel station locations	Station ID# in Figure 3.1-1
Sacramento River at Greenes Landing and Hood	2
Mokelumne River at Georgiana Slough	411
Little Potato Slough at Terminous Island	414
False Tip at Webb Tract	131
Connection Slough at Mandeville Island	115
Sandmound Slough	113
Contra Costa Water District Pumping Plant #1	133
Rock Slough at Old River	9
Station 04B on Old River	100
Middle River at Bacon Island	110
Station 09 at Old River	103
Santa Fe Dredge Cut at Bacon Island	117
Clifton Court Forebay gate	10
Delta Mendota Canal intake at the Tracy Pumping Plant	11

In channels at or near the DWP island intakes, the DOC concentrations are generally higher during the winter (January – March) than in the summer due to runoff and upstream releases. Winter DOC at the Mokelumne River station, located upstream of Webb Tract, ranged from 2 to 6 mg/l. Winter DOC levels at stations near Bacon Island and Holland Tract were:

- 5.2 – 5.3 mg/l at the Connection Slough at Mandeville Island station
- 4.7 – 9.0 mg/l at the Middle River at Bacon Island station
- 3.8 – 4.6 mg/l at Station 04B on Old River
- 3.5 – 5.0 mg/l at the Rock Slough near Old River station
- 3.7 – 8.8 mg/l at Station 09 on Old River
- 4.1 – 5.7 mg/l at the Santa Fe Cut at Bacon Island station

At the southern Delta export stations that may be affected by the DWP releases, the summer (July – September) DOC concentrations were:

- 2.6 – 4.2 mg/l at the Clifton Court Forebay intake
- 3.8 – 4.5 mg/l at the DMC intake station
- 1.8 – 4.2 mg/l at the CCWD Pumping Plant #1 station

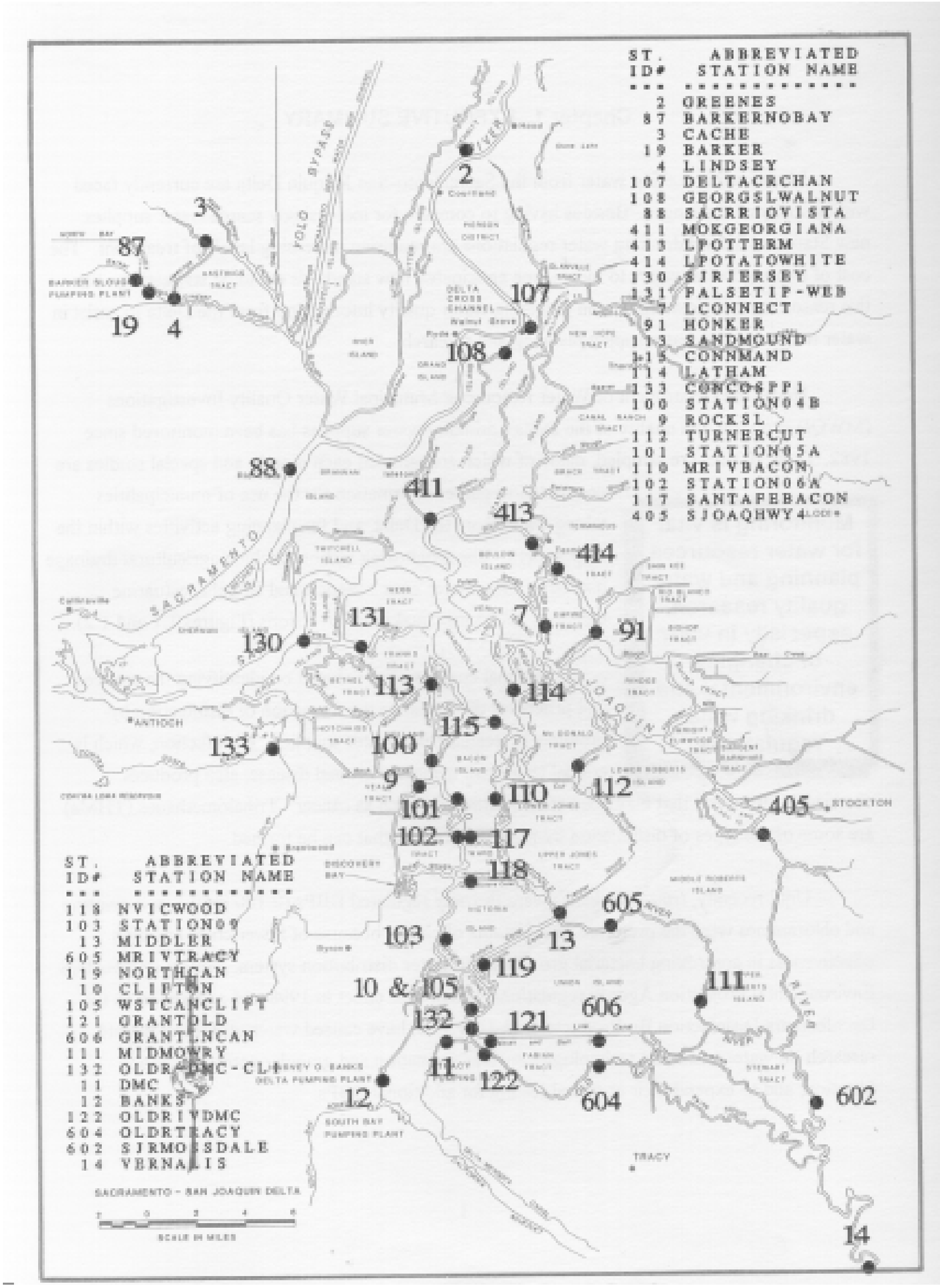


Figure 3.1-1. MWQI Channel Stations

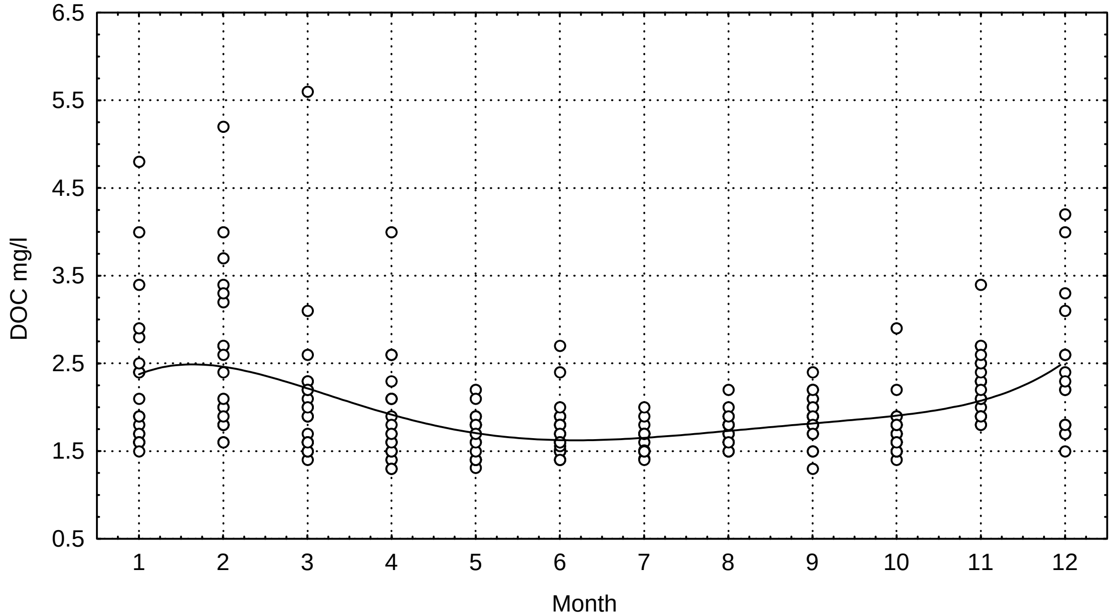
The monthly DOC, UVA 254nm, and specific absorbance values for the selected 14 Delta stations are presented in the following figures (Figures 3.1-1 to 3.1-14). The statistical software program STATISTICA for Windows release 5.5 (Statsoft, 2000) was used to plot the data. A nonlinear polynomial regression line was fitted over the scatter plot data points for visualization purposes to compare the relationships among the three variables. The polynomial model was fitted via a fifth order least squares regression (Neter et. al., 1985) of the observed data. In cases where monthly data were available, the general trends of the line appeared reasonable. In cases with few data, the lines indicated more data was needed to discern general trends. Continued data collection at these sites would enhance future modeling efforts by the Department.

In general, UVA 254nm readings correlated with DOC concentrations. Both DOC and UVA 254nm in the Delta channels are highest in the wet winter months (October – April) and lowest during the dry months (May – September). The largest variability or range in DOC concentrations occur in the wet months due to storms and upstream releases and runoff.

The specific UV absorbance (SUVA), which is computed by the ratio of the UVA 254nm reading (per cm) to the DOC concentration (mg/l) by 100[1], is used as a semi-qualitative and semi-quantitative indicator of the humic fraction of dissolved organic carbon in water. Humic or high UV absorbing organic matter is typically found in drainage from the organic rich peat islands of the Delta. The influence of seasonal Delta island drainage discharges on the DOC quality of the interior Delta can be seen in the monthly specific UV absorbance scatter plots. The highest SUVA values (3 and greater) in the Delta channels frequently occur during the winter and summer when drainage discharges increase. Winter island drainage is high due to the combined events of leaching the fields, rainfall, and increased seepage return water pumped off the islands. The peak summer period for agricultural drainage discharge from the Delta islands occurs in July and August. Lower SUVA values are observed in the spring and fall when drainage discharges are the lowest.

More information about Delta island drainage volumes and organic carbon loads have been presented in several DWR MWQI reports (DWR, 1994; Jung and Tran, 1998; Jung and Tran, 1999; Jung, 2000).

[1] In this report, SUVA = (UVA 254nm/DOC) x 100. In some literature, SUVA = (UVA 254nm/DOC).



Scatterplot (riverwq STA 11v*3451c)

Figure 3.1-2b. Sacramento River at Greenes Landing and Hood UVA

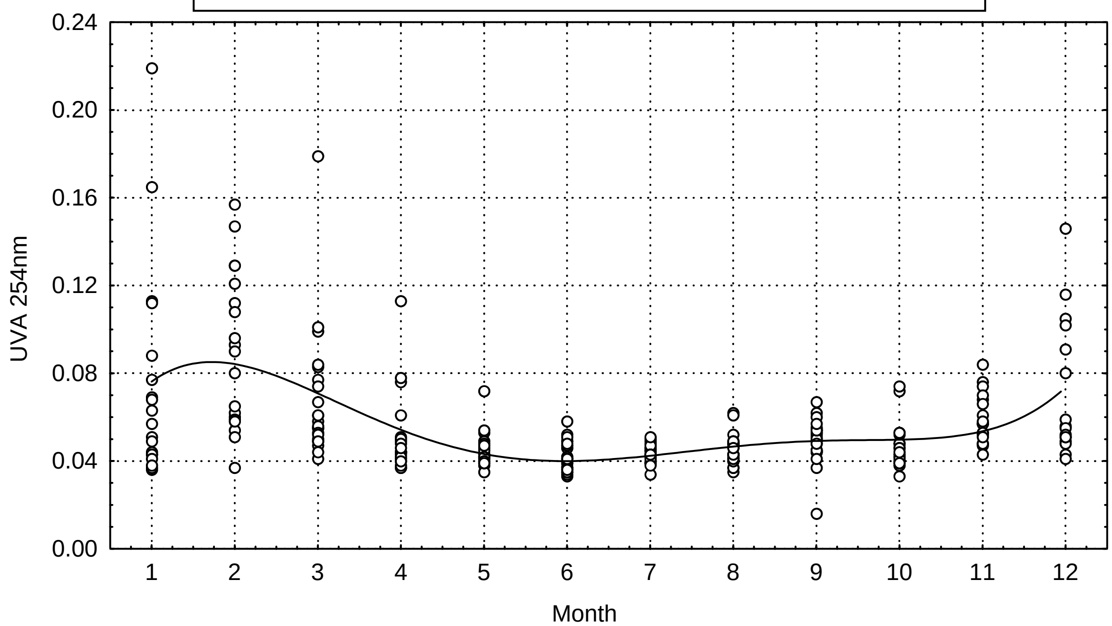
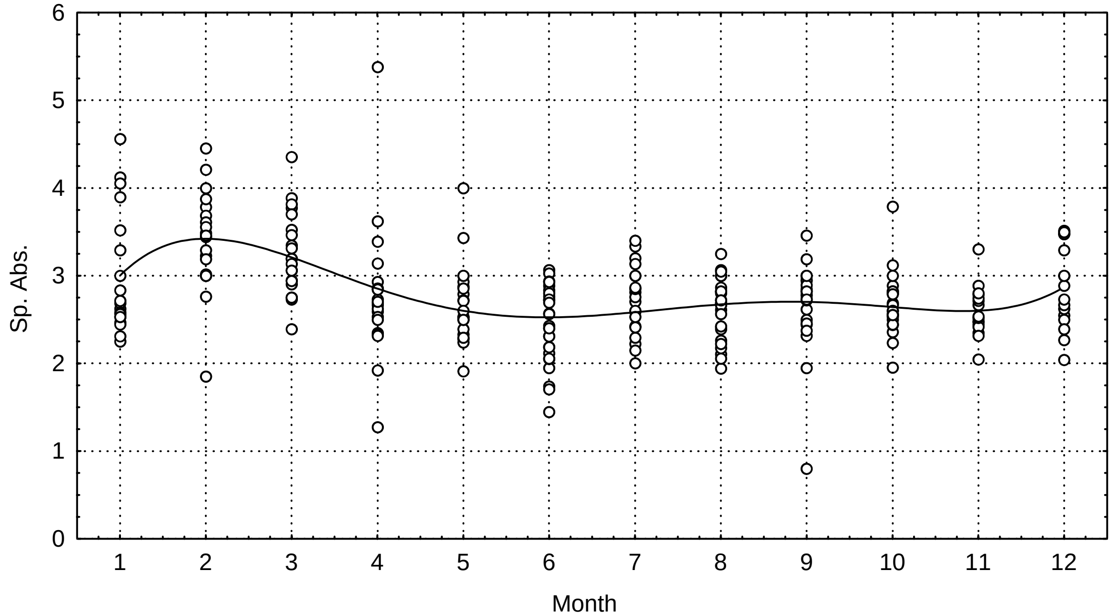
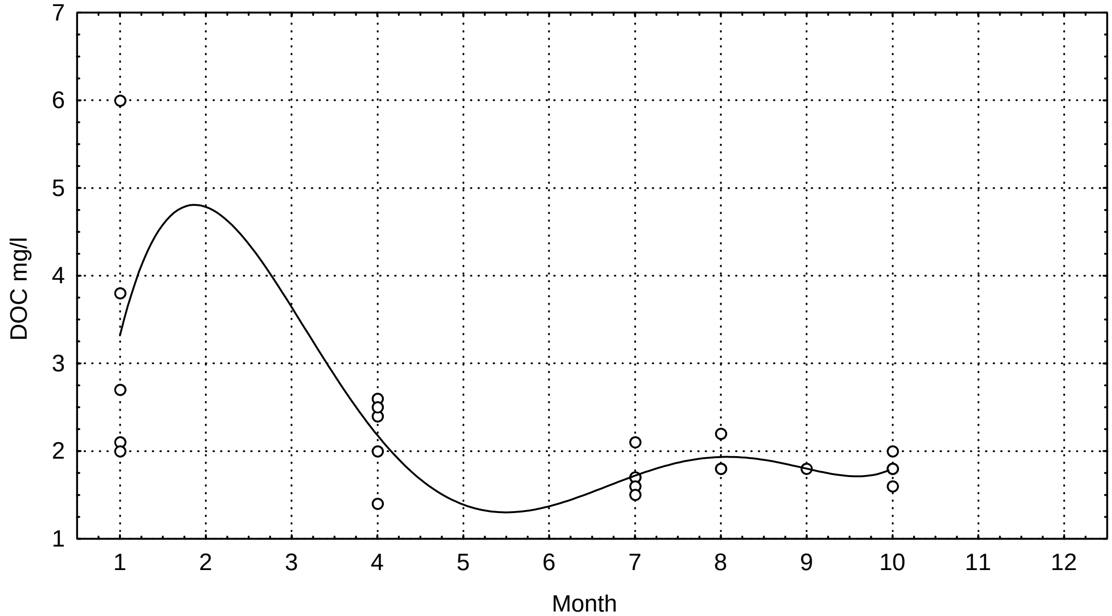


Figure 3.1-2e: Sacramento River at Greenes Landing and Hood Specific Absorbance





Scatterplot (riverwq STA 11v*3451c)

Figure 3.1-3b: Mokelumne River at Georgiana Slough UVA

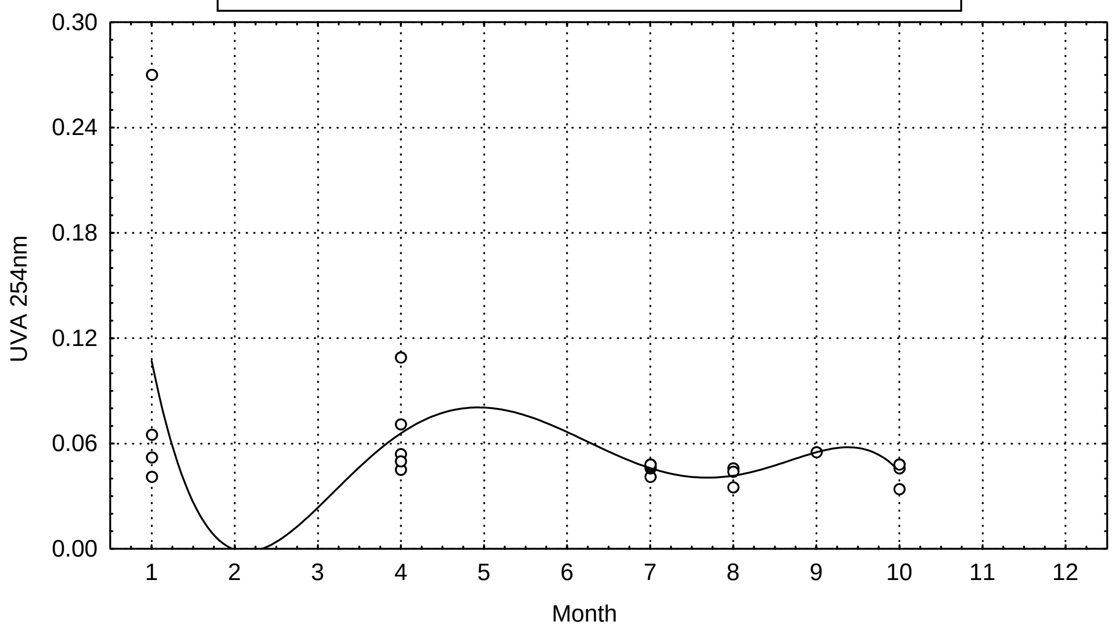
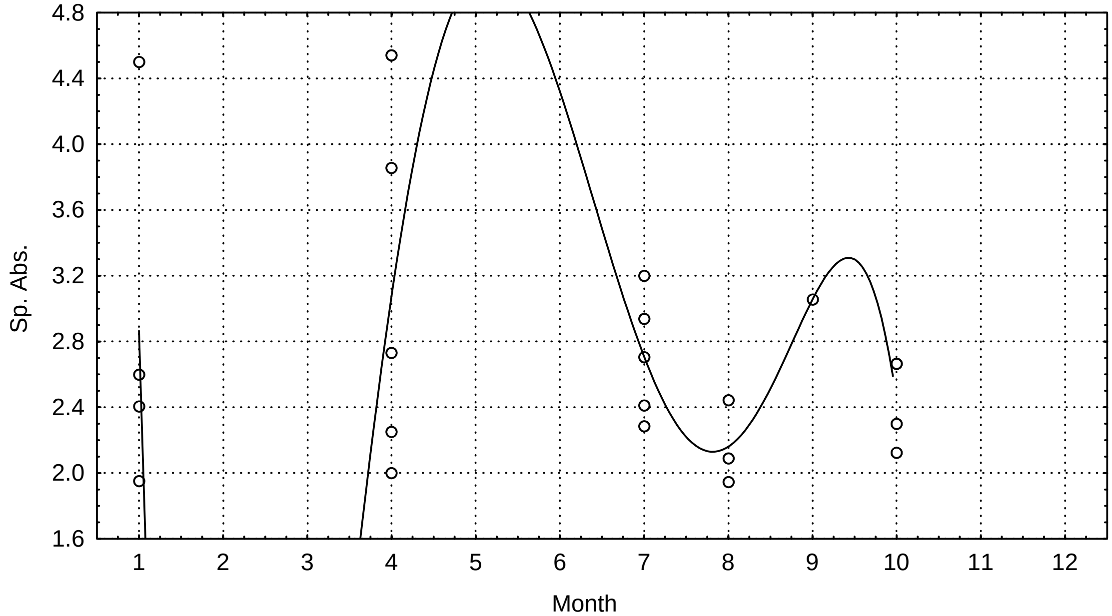
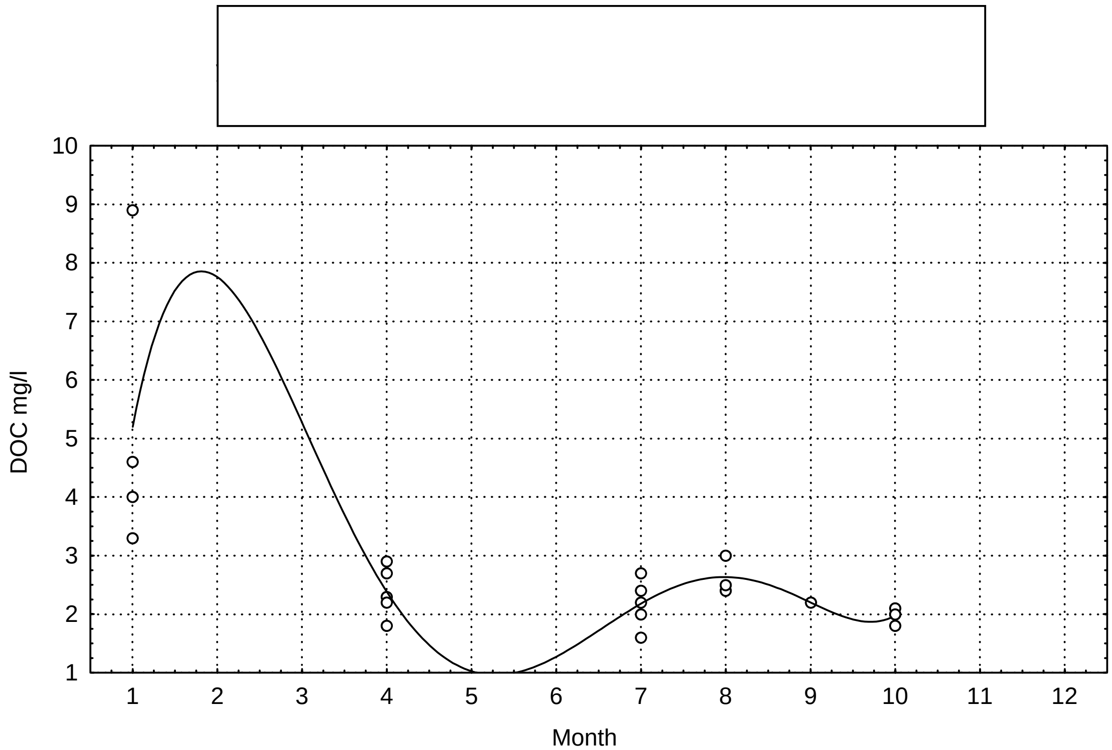


Figure 3.1-3c. Mokelumne River at Georgiana Slough Specific Absorbance





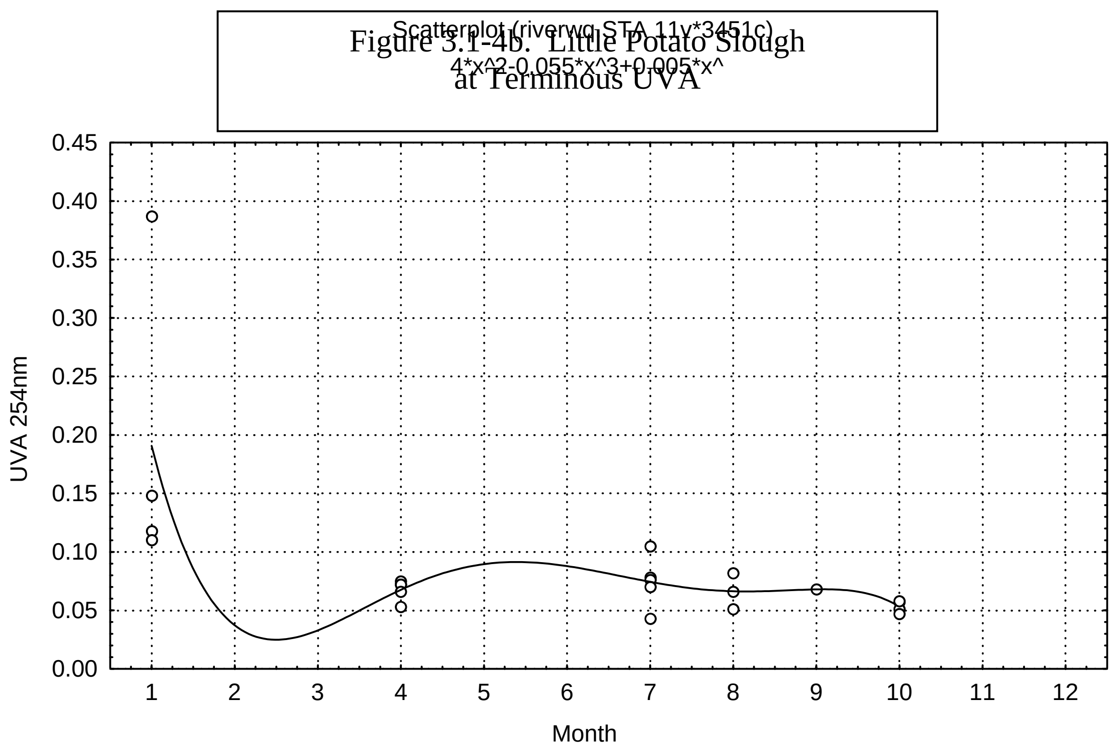
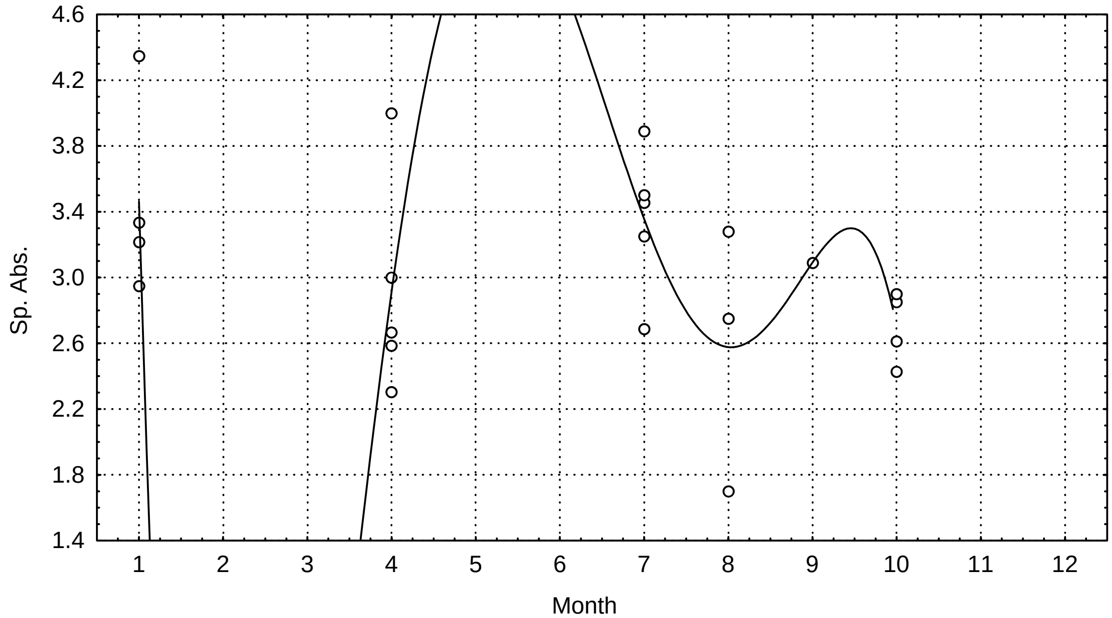
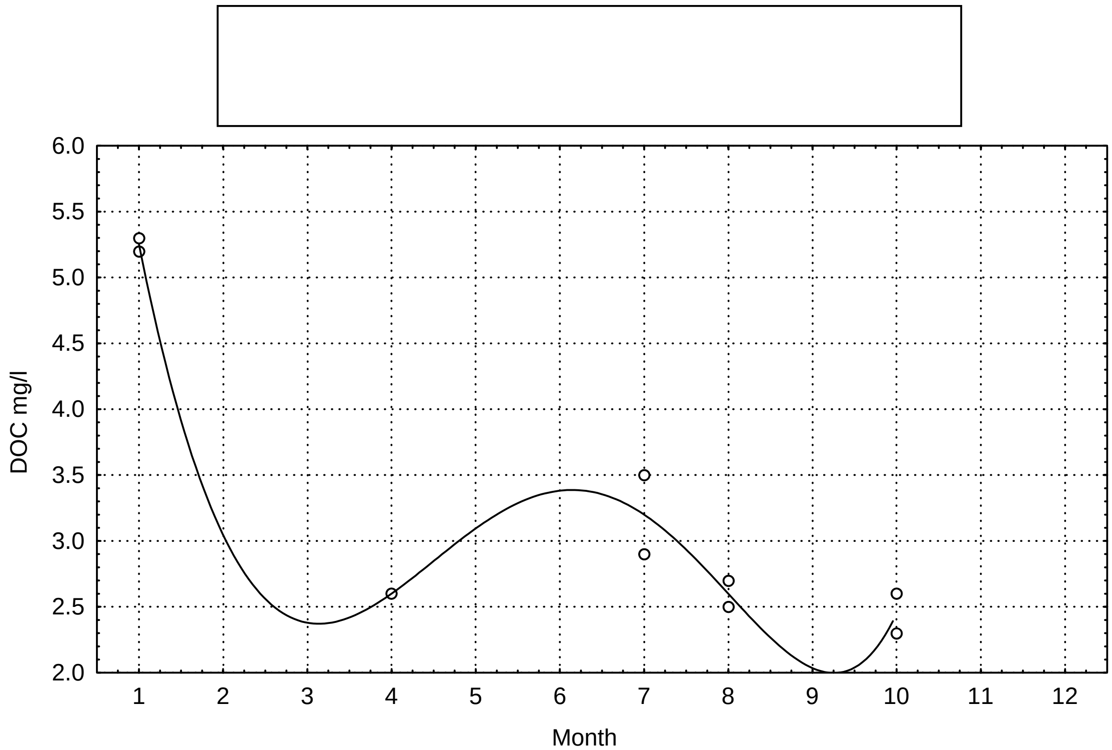


Figure 3.1-4b. Little Potato Slough at Terminous UVA

Figure 3-1-4c. Little Potato Slough
at Terminous Specific Absorbance





Scatterplot (riverwq STA 11v*3451c)

Figure 3.1-5b. Connection Slough at Mandeville UVA

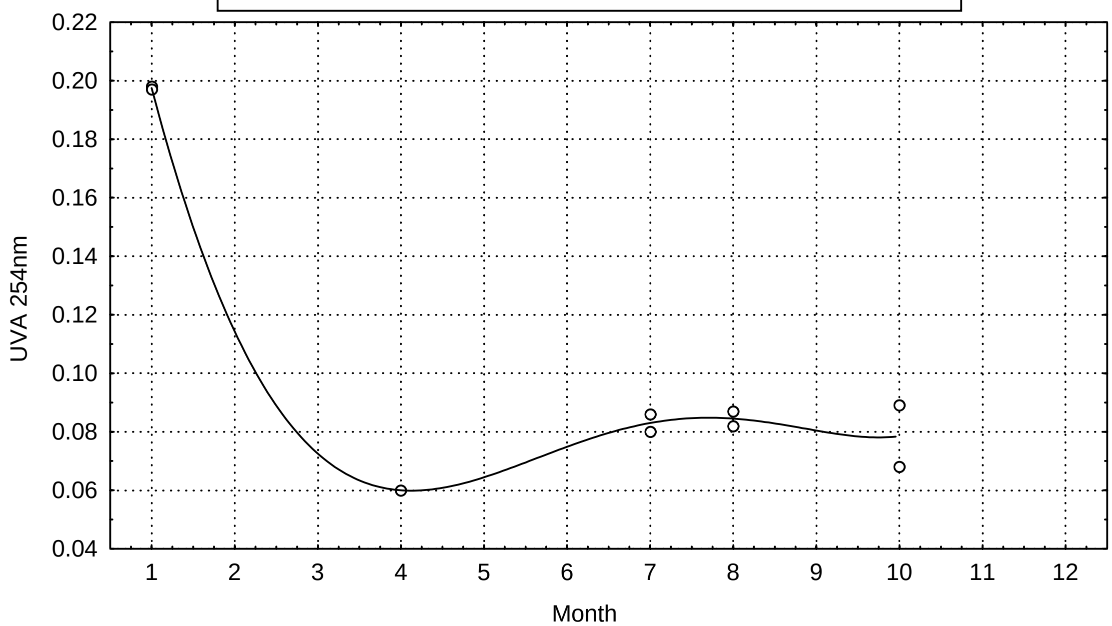
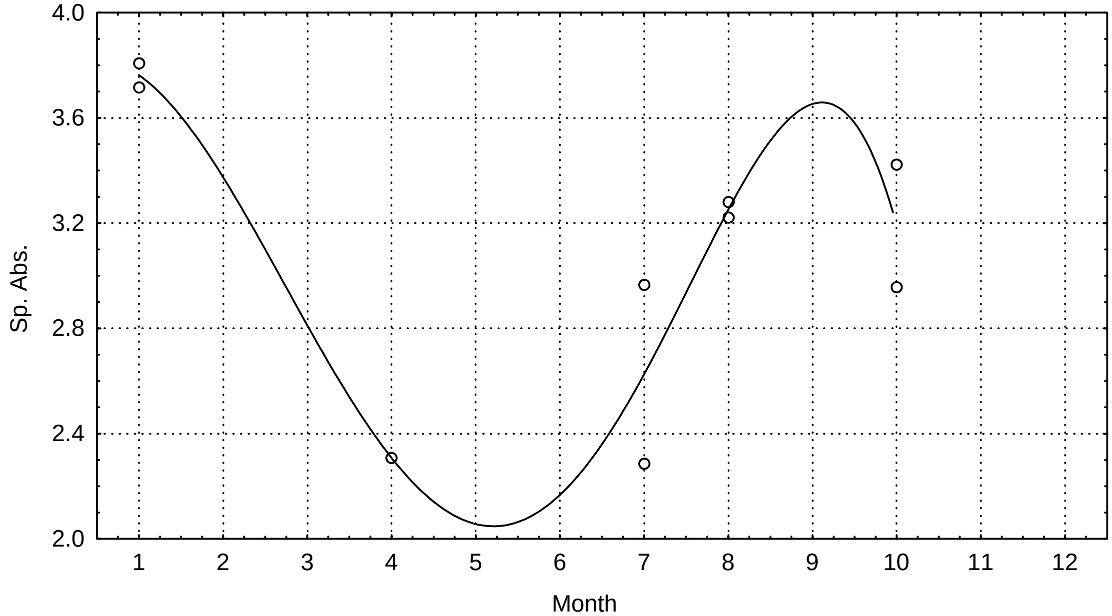


Figure 3.1-5c. Connection Slough
at Mandeville Specific Absorbance



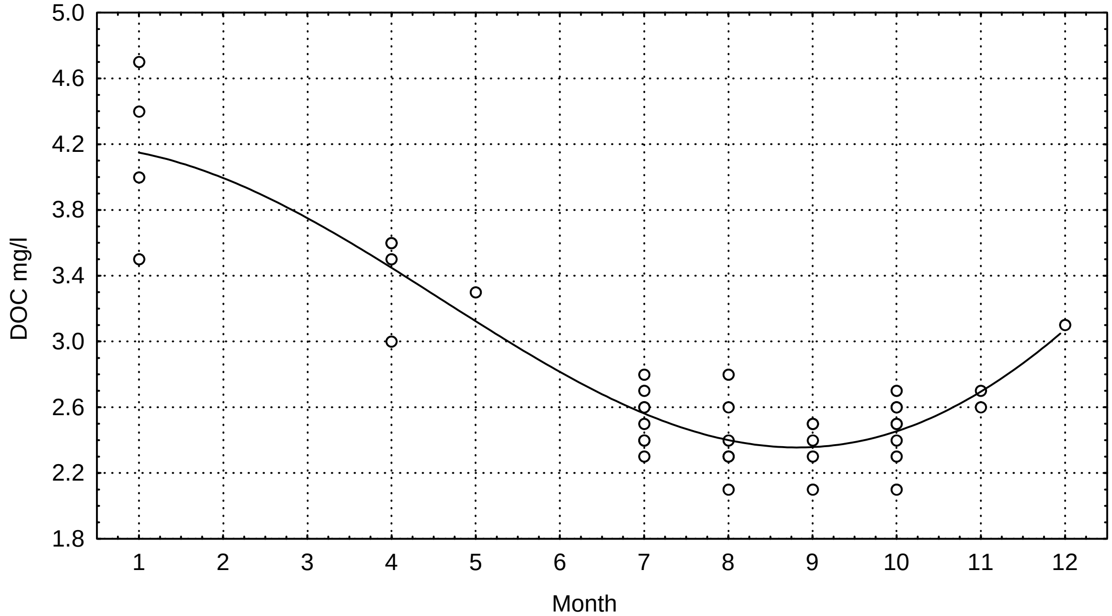


Figure 3.1-6b. Sandmound Slough UVA

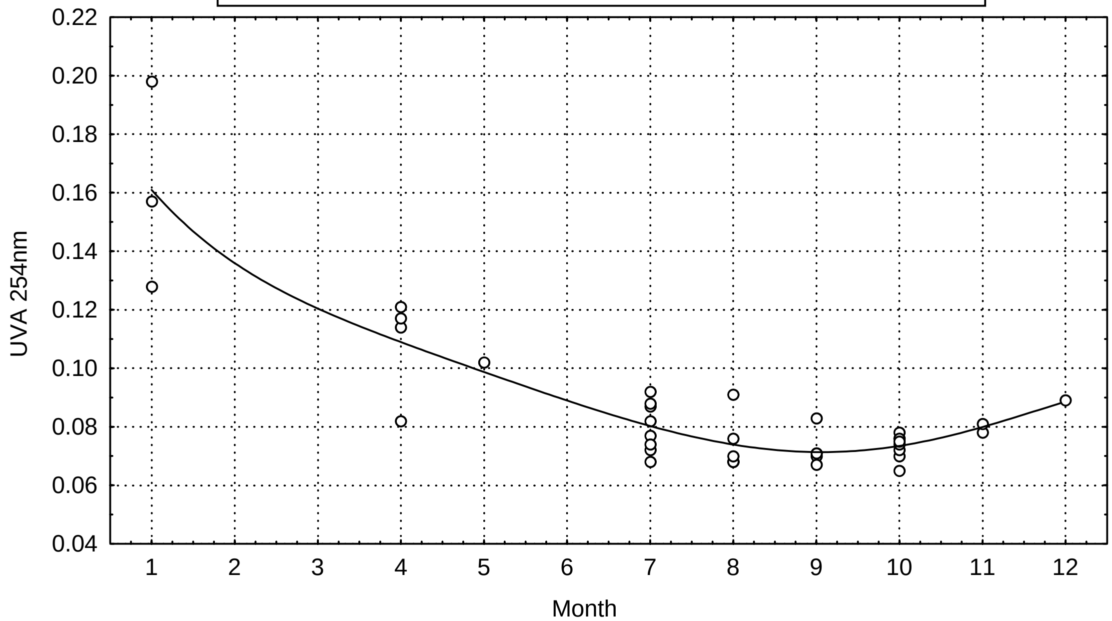
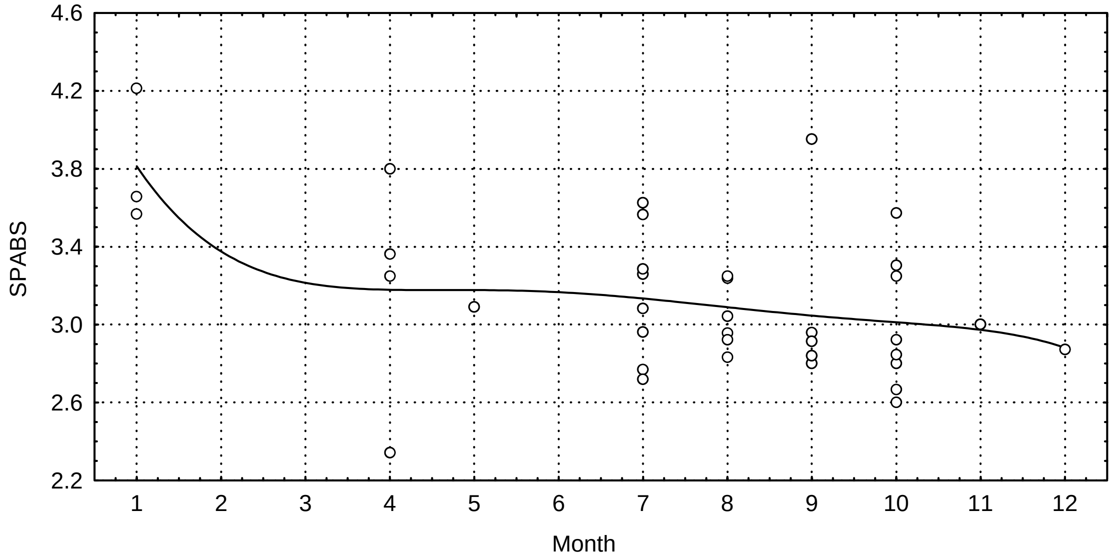


Figure 3.1-6c. Sandmound Slough
Specific Absorbance



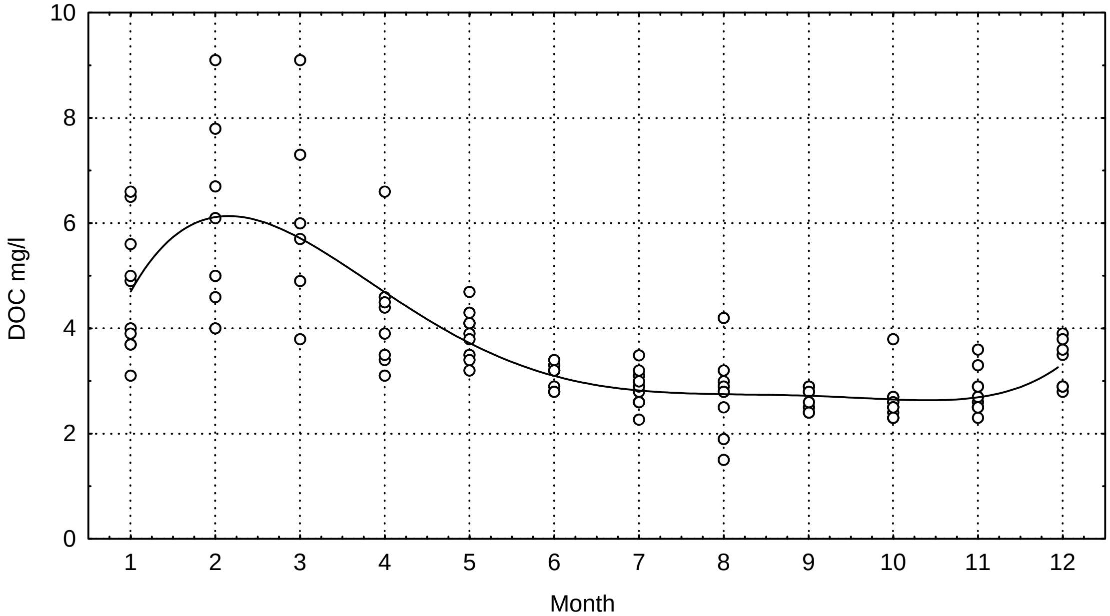


Figure 3.1-7b: GCWD Pumping Plant #1
UVA

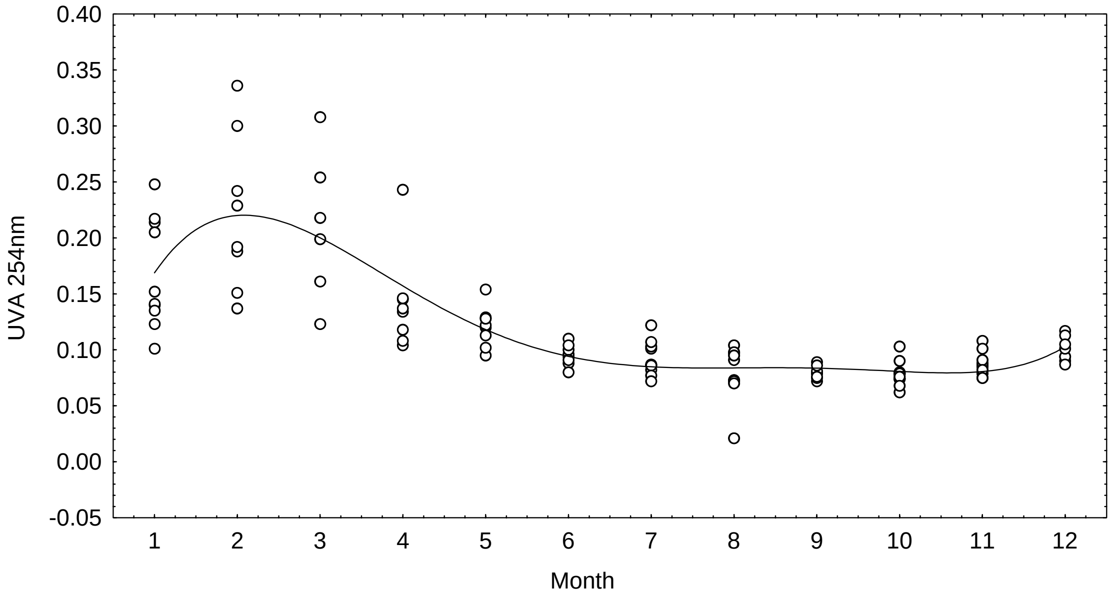


Figure 3.1-7e. CCWD Pumping Plant #1
Specific Absorbance

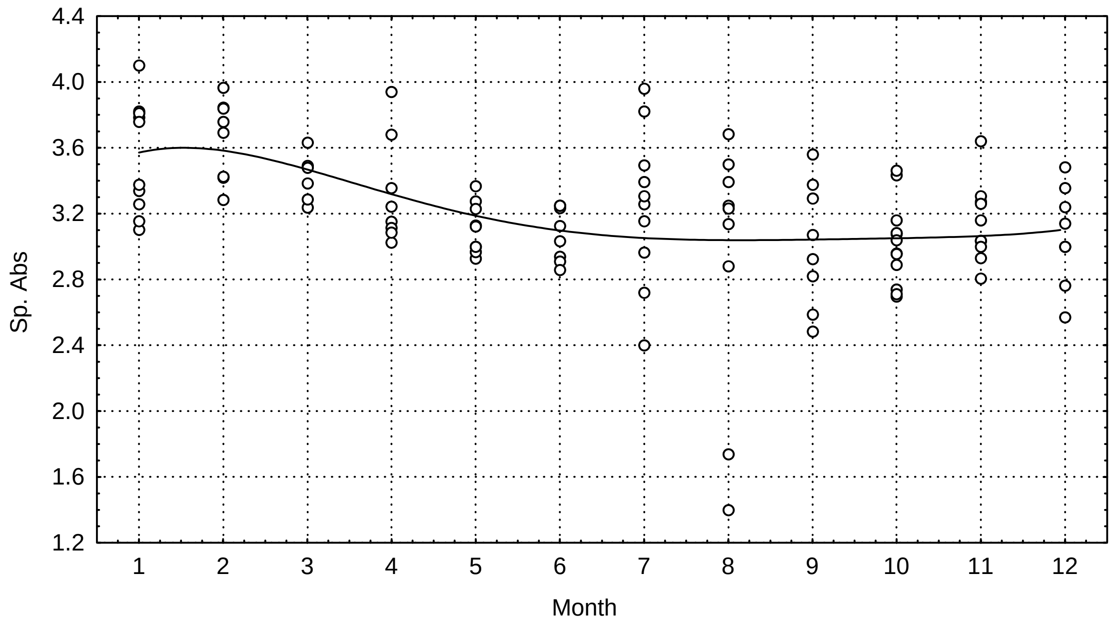


Figure 3.1-8a. Rock Slough at
Old River DOC

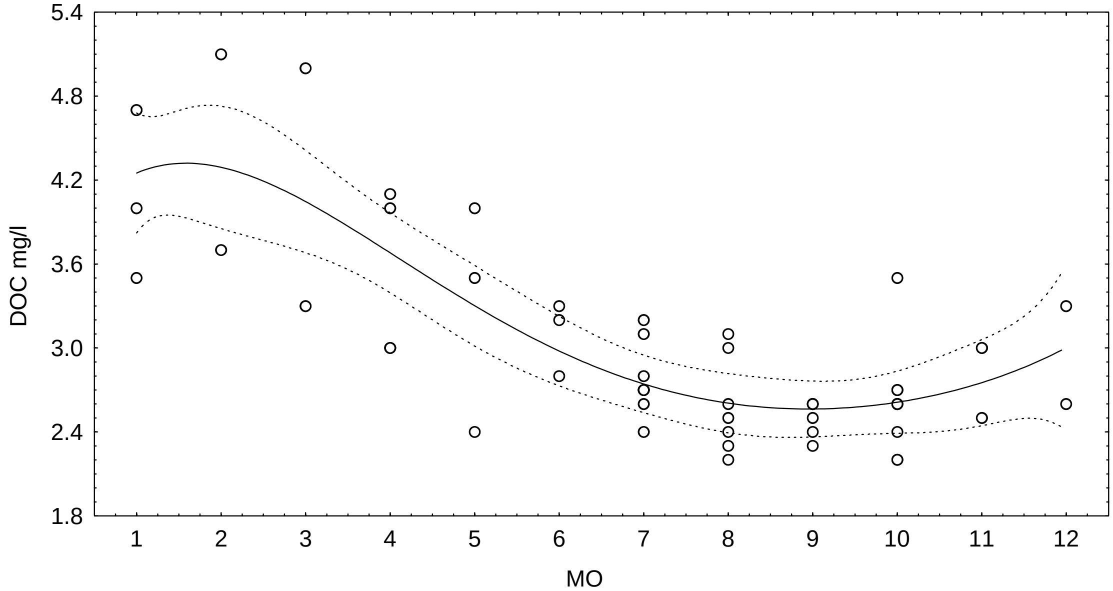


Figure 3.1-8b. Rock Slough at
Old River UVA

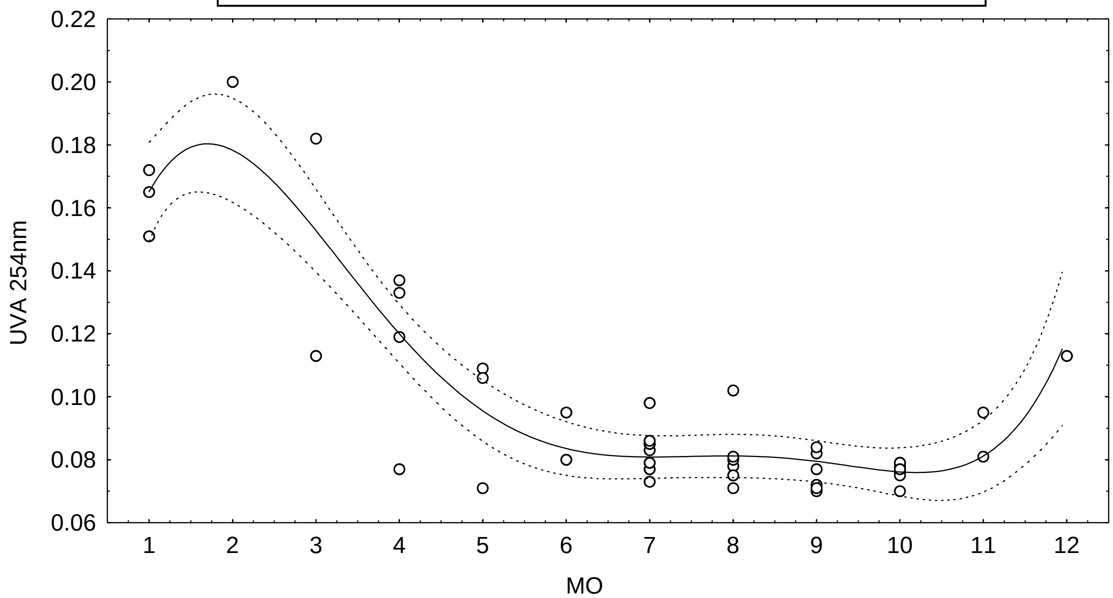


Figure 3.1-8c. Rock Slough at
Old River Specific Absorbance

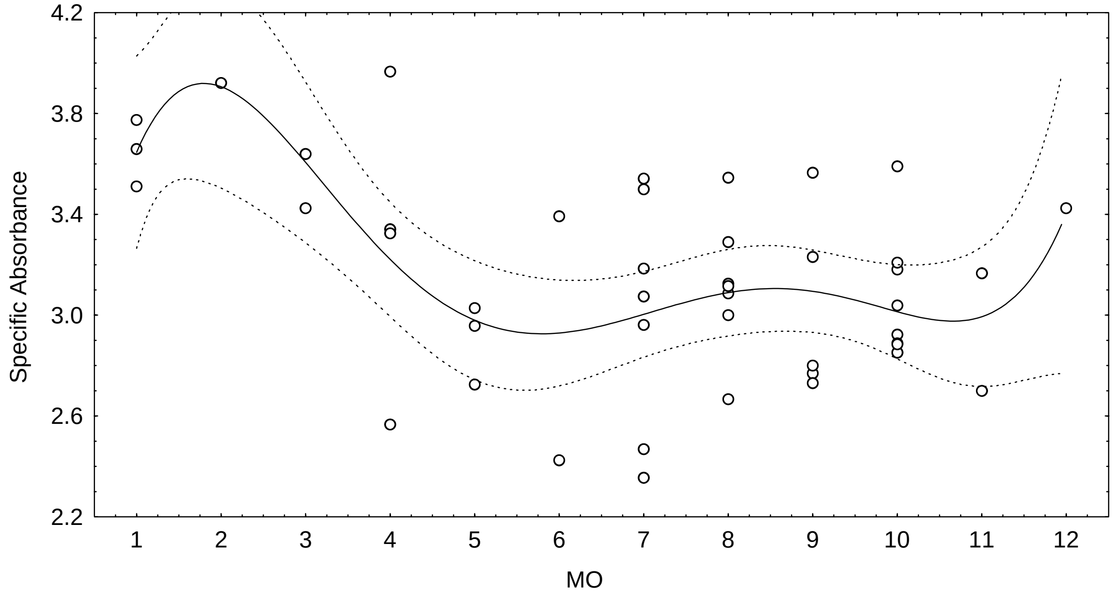


Figure 3.1-9a. Station 04B
on Old River DOC

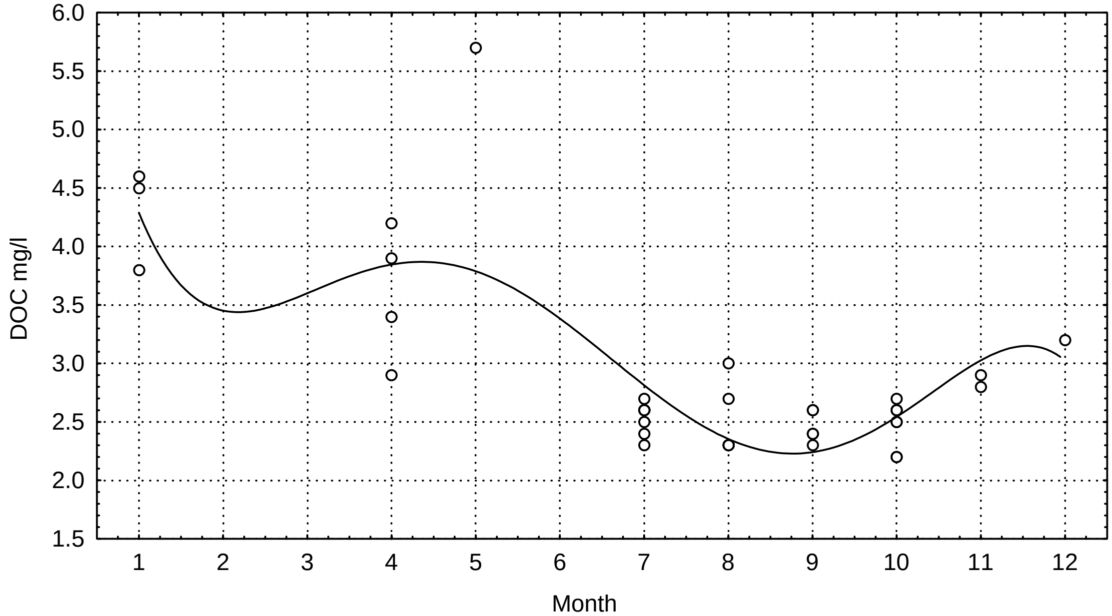


Figure 3.1-9b. Station 04B
on Old River UVA

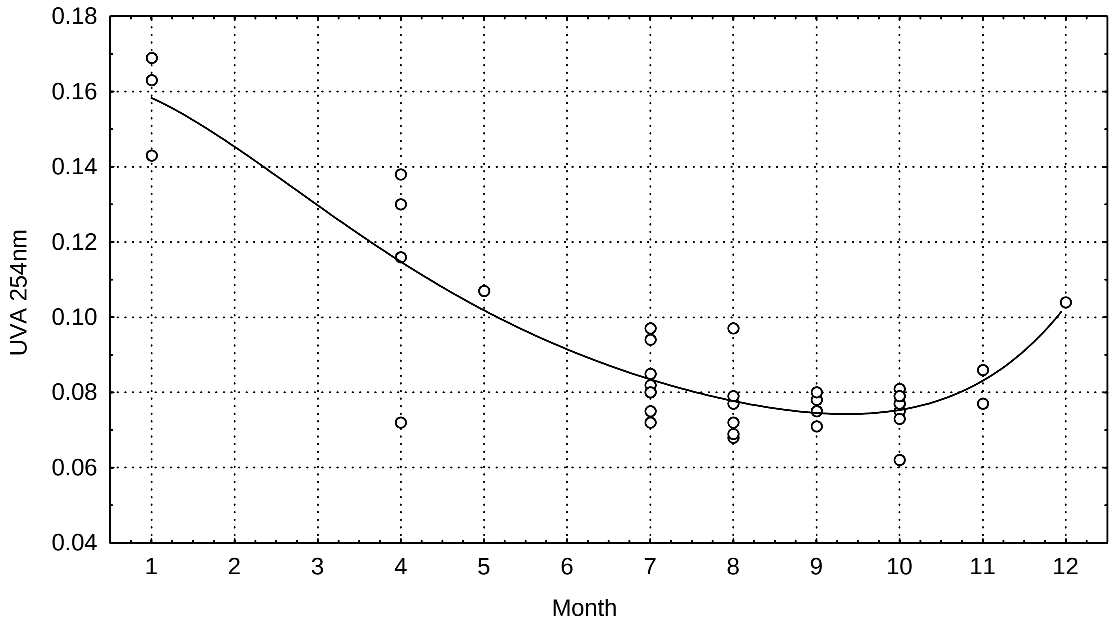
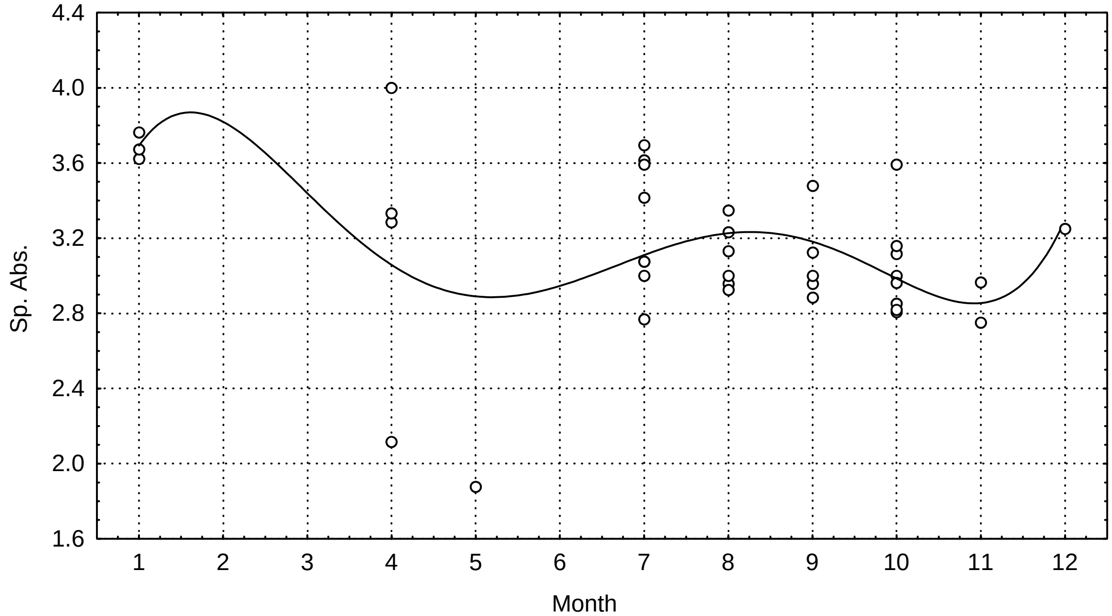
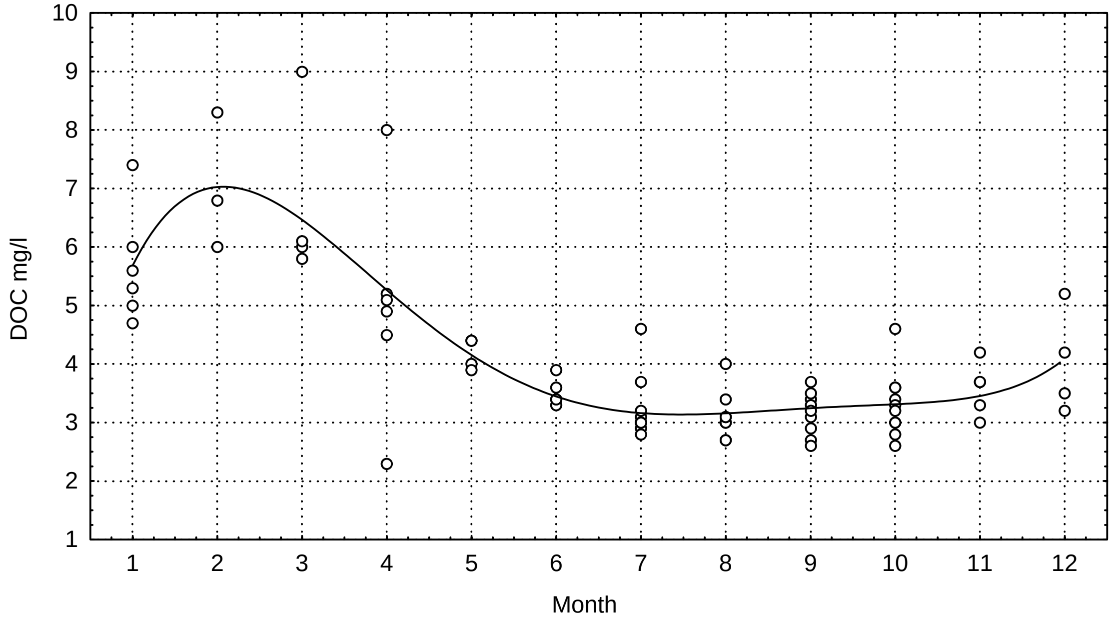


Figure 3.1-9c Station 04B
on Old River Specific Absorbance





Scatterplot (riverwq STA 11v*3451c)
Figure 3.1-10b. Middle River at Bacon UVA

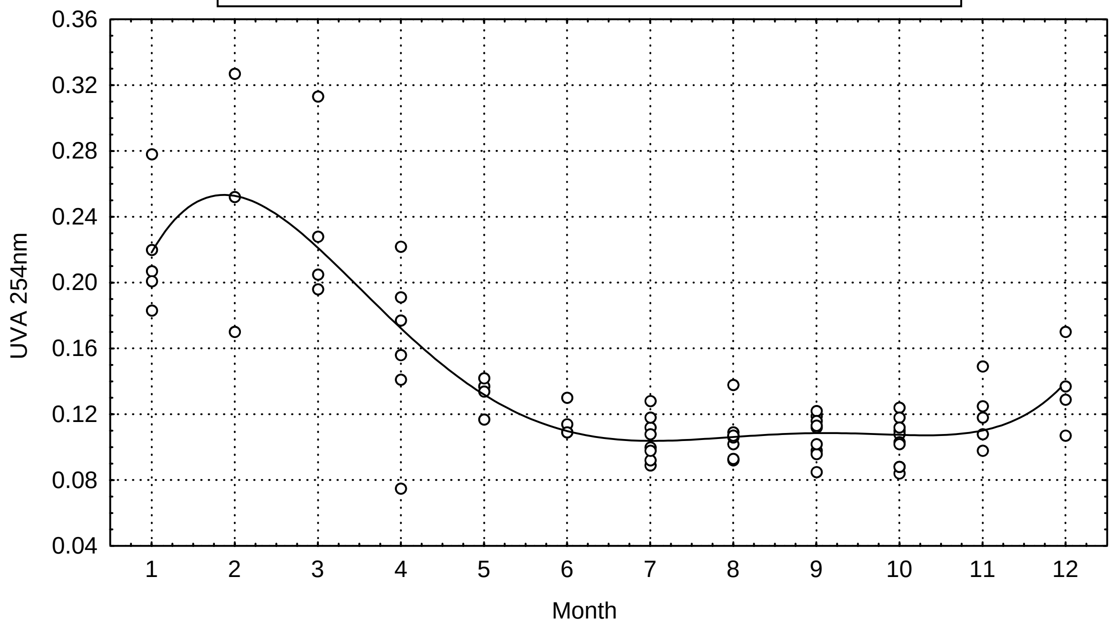


Figure 3.1-10c Middle River at Bacon Specific Absorbance

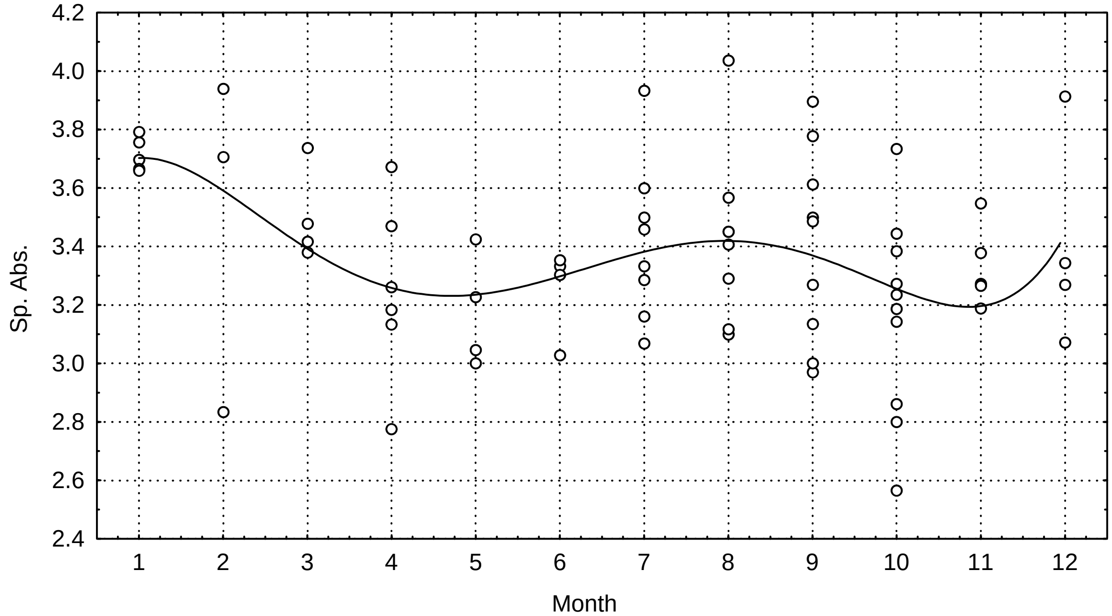
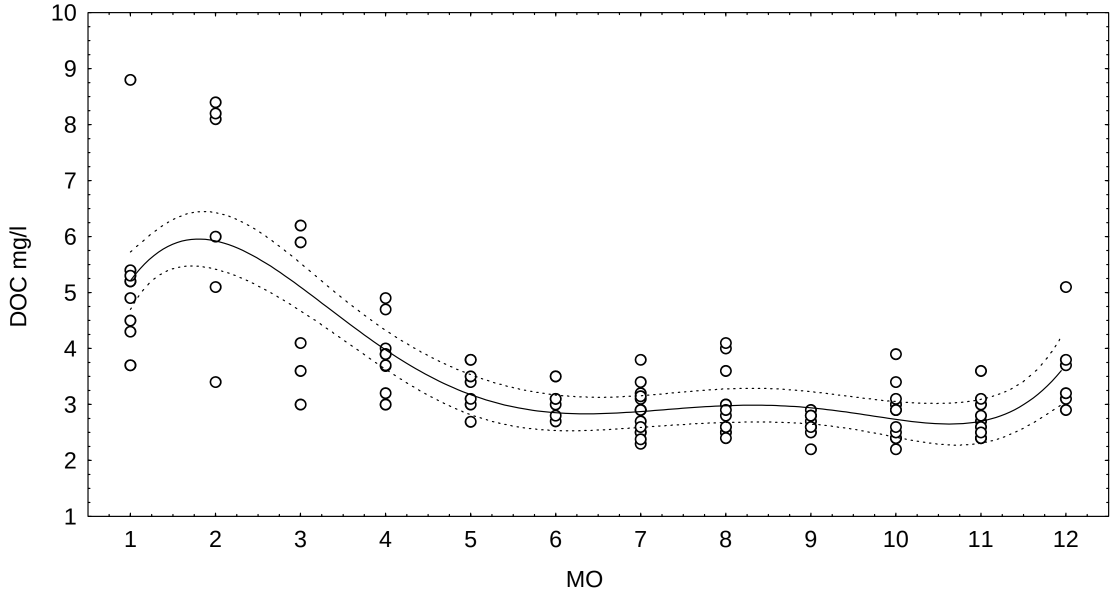


Figure 3.1-11a. Station 9 at
Old River DOC



atterplot (riverwq.STA 11v*3451c)
Figure 3.1-11b. Station 9 at
Old River UVA

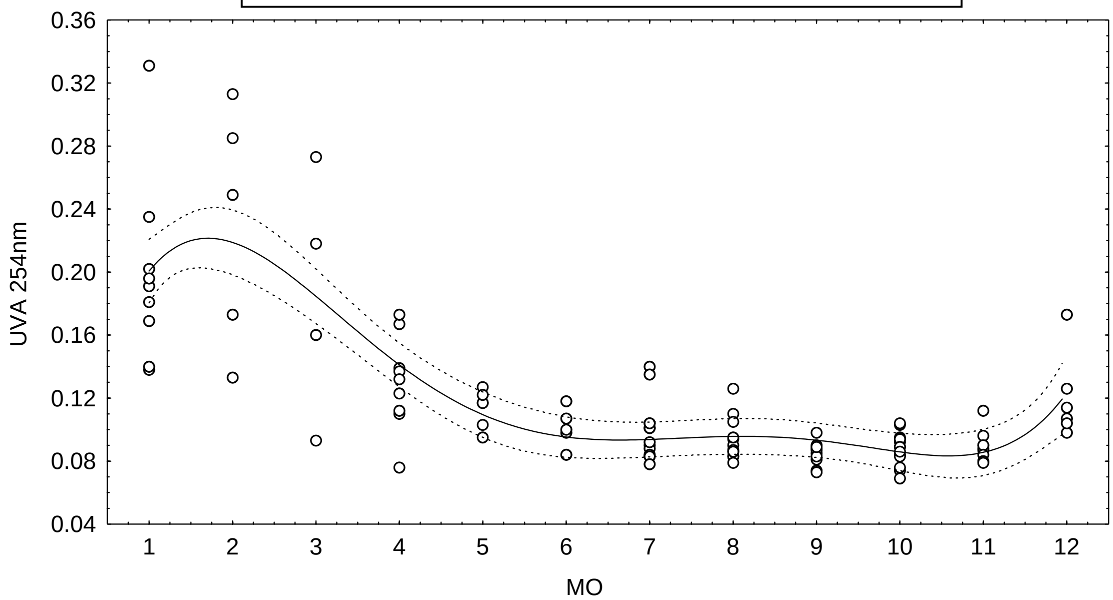


Figure 3.1-11c. Station 9 at
Old River Specific Absorbance

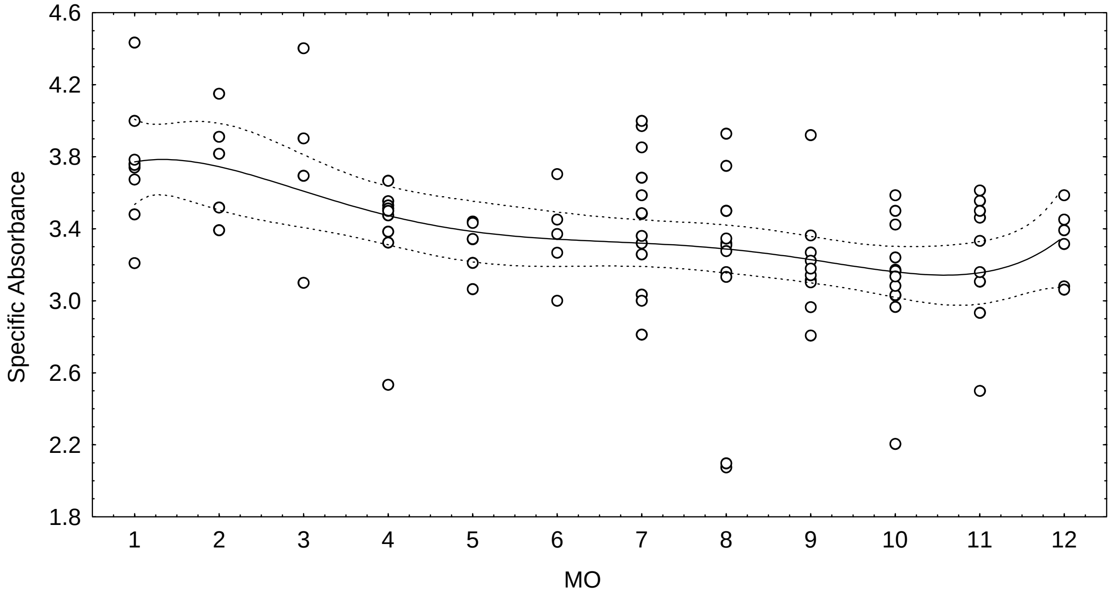
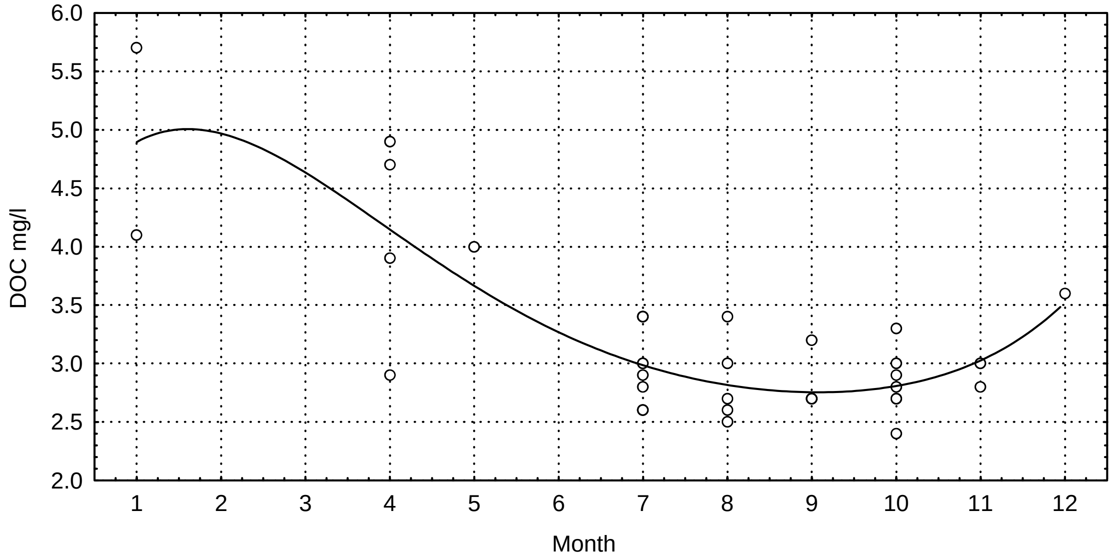


Figure 3.1-12a. Santa Fe Canal
at Bacon DOC



Scatterplot (riverwq.STA 11v*3451c)

Figure 3.1-12b. Santa Fe Canal
at Bacon UVA

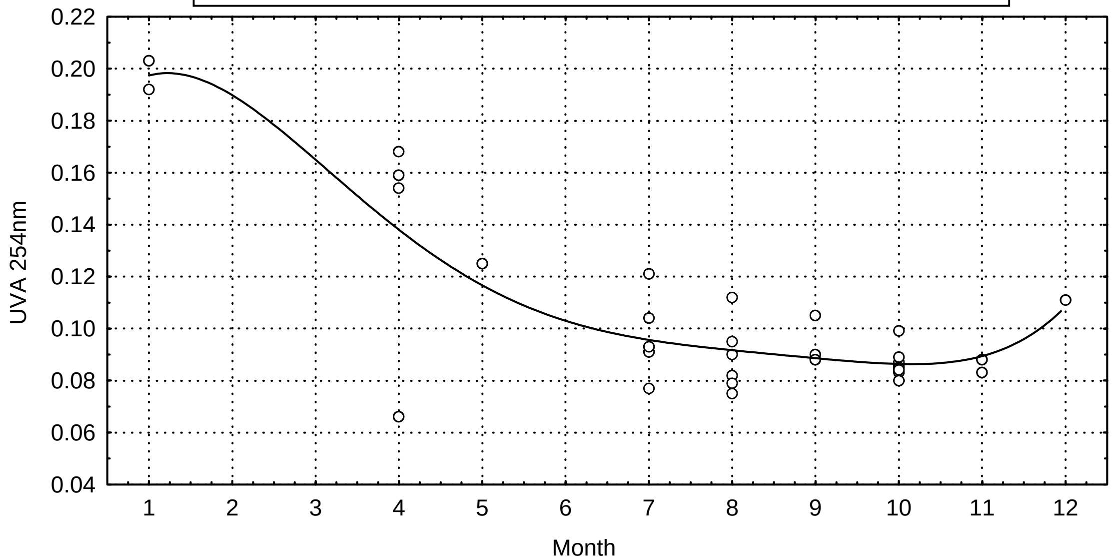
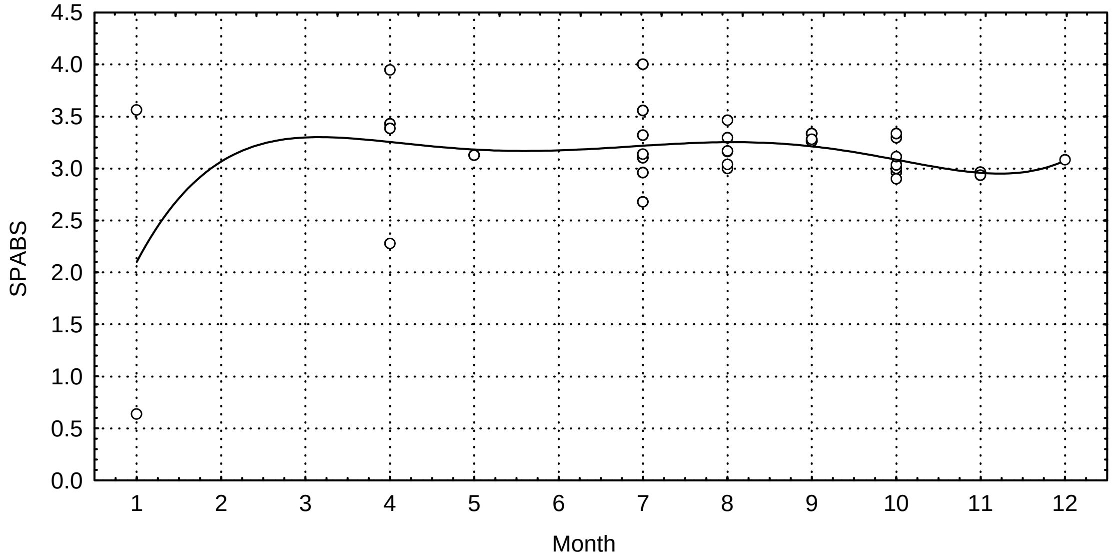
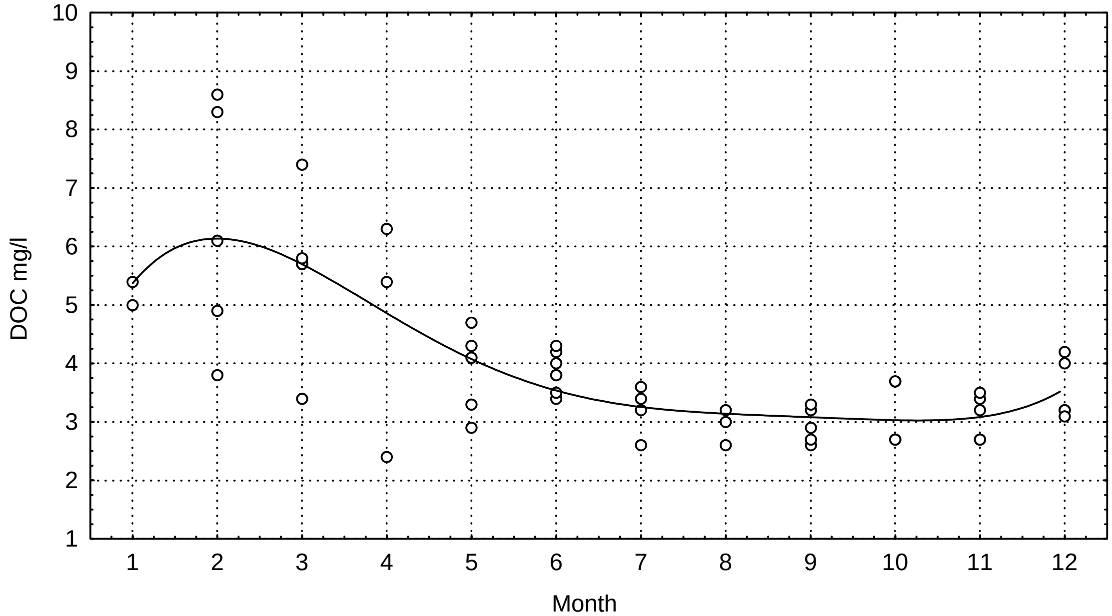


Figure 3.12c. Santa Fe Canal
at Bacon Specific Absorbance





Scatterplot (riverwq.STA 11v*3451c)

Figure 3.13b. Clifton Court Forebay gate UVA

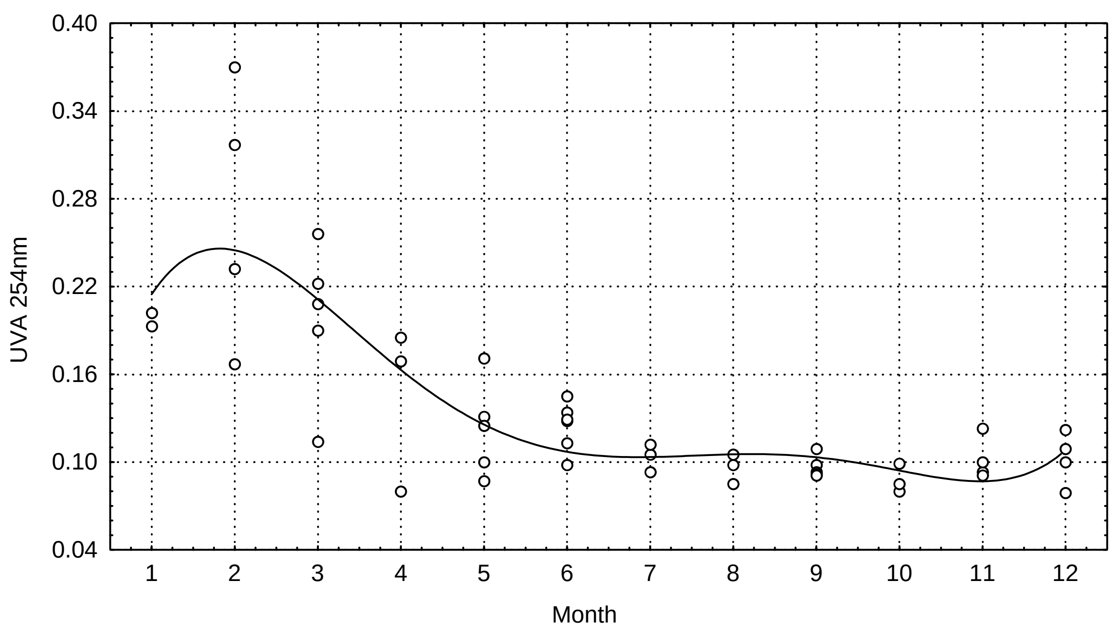


Figure 3.13c: Clifton Court Forebay gate Specific Absorbance

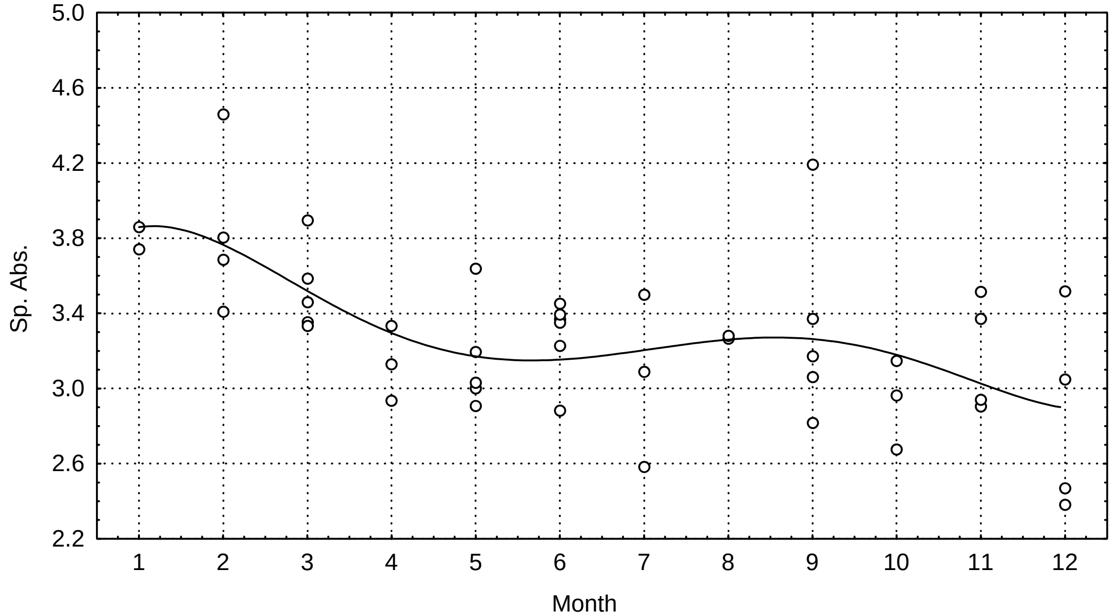
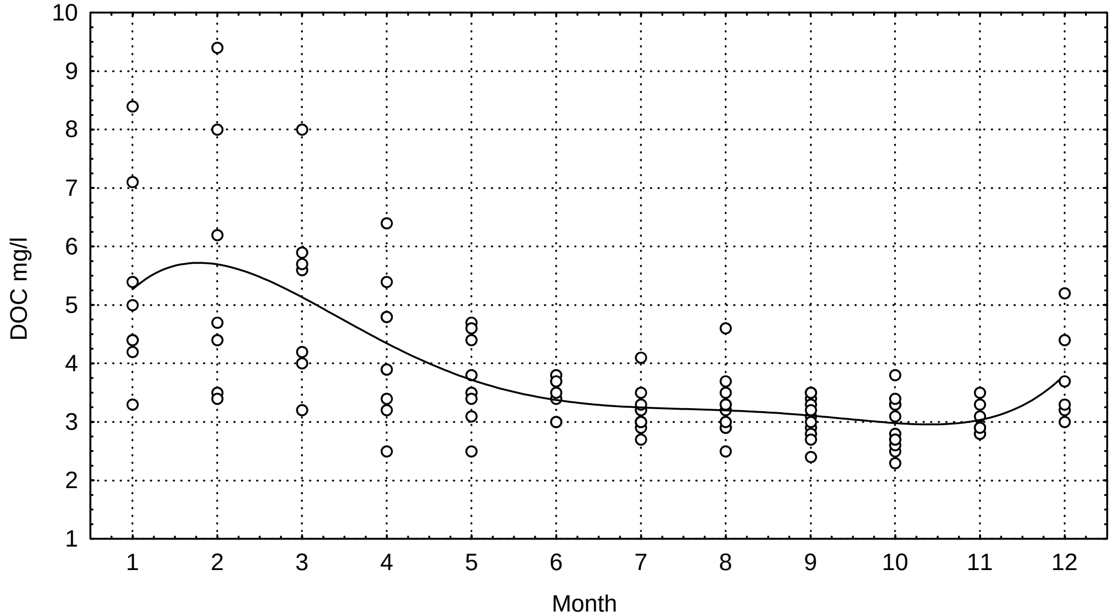


Figure 3.14a. DMC intake at
Tracy PP DOC



catterplot (riverwq.STA 11v*3451c)

Figure 3.14b. DMC intake at
Tracy PP UVA

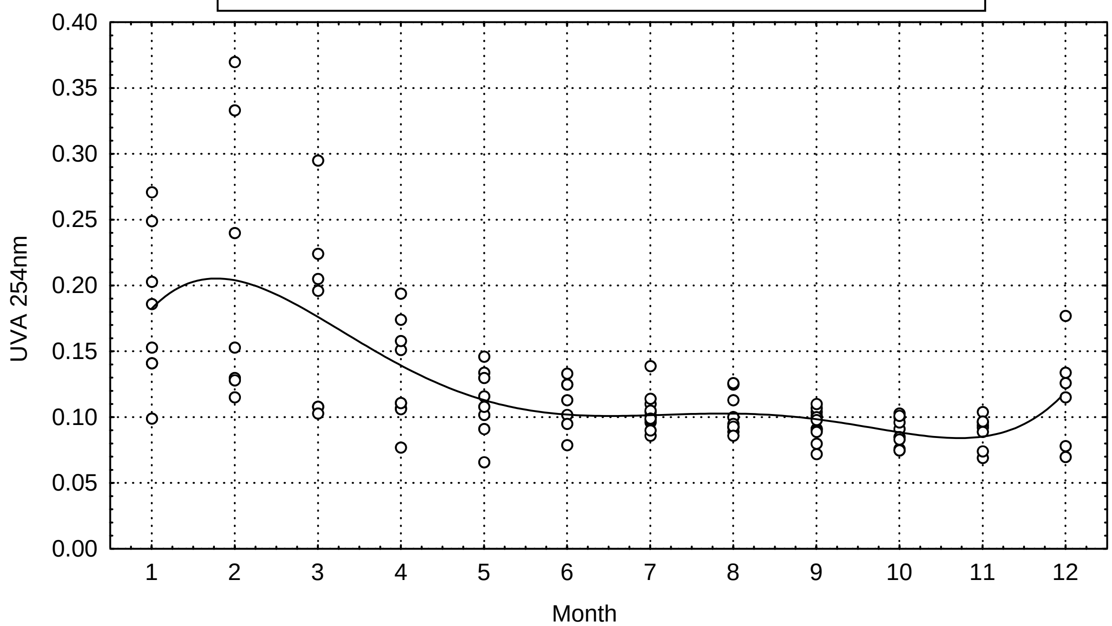
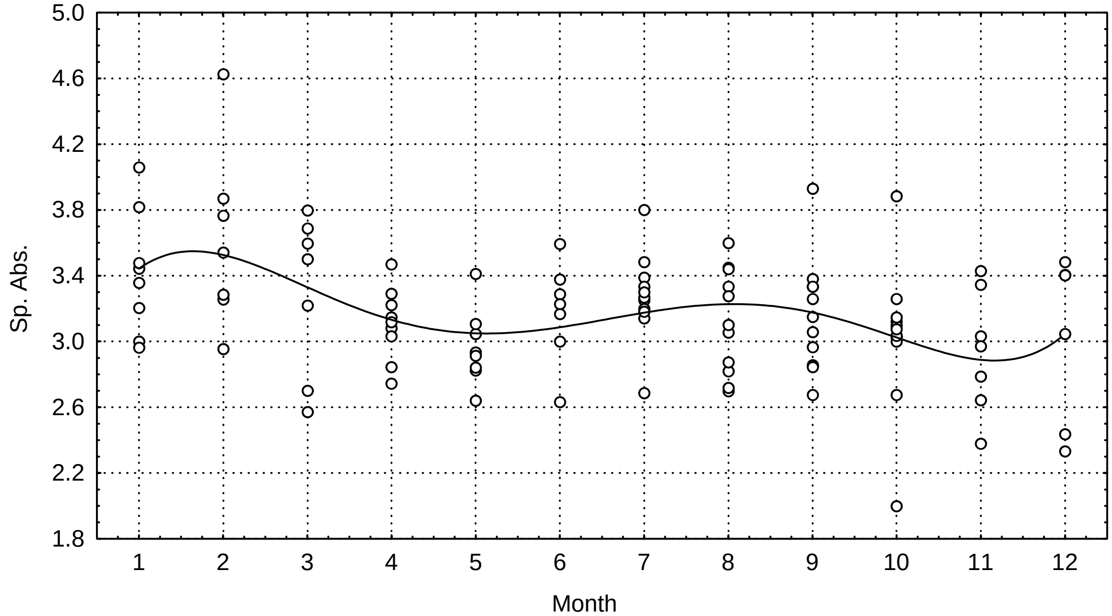


Figure 3.1-14c. DMC intake at
Tracy PP Specific Absorbance



3.2. Agricultural drainage water quality

The DOC concentrations of the agricultural drainage water were compared to assess the relative potential levels of DOC that might become available from the peat soils when flooded. The highest DOC concentrations are expected during water saturated conditions and with long soil-to-water contact times such as in the winter. In the late fall – winter, the fields are ponded to decompose crop residues and to leach salts that had built-up in the root zone during the hot summer irrigation period. DOC concentrations in drainage are typically lower in the summer when drainage is constantly removed and soil-to-water contact times are short because of applied irrigation water. The comparison of island drainage water quality by peak monthly DOC concentrations has been used to map regional differences in DOC loads for simulated runs in the DWR Delta Island Consumptive Use (DICU) Model and DSM2 model (Jung and Tran, 1999; Jung, 2000). Correlations of EC and mineral constituents by region were also presented in Consultant's report #3 (Jung, 2000).

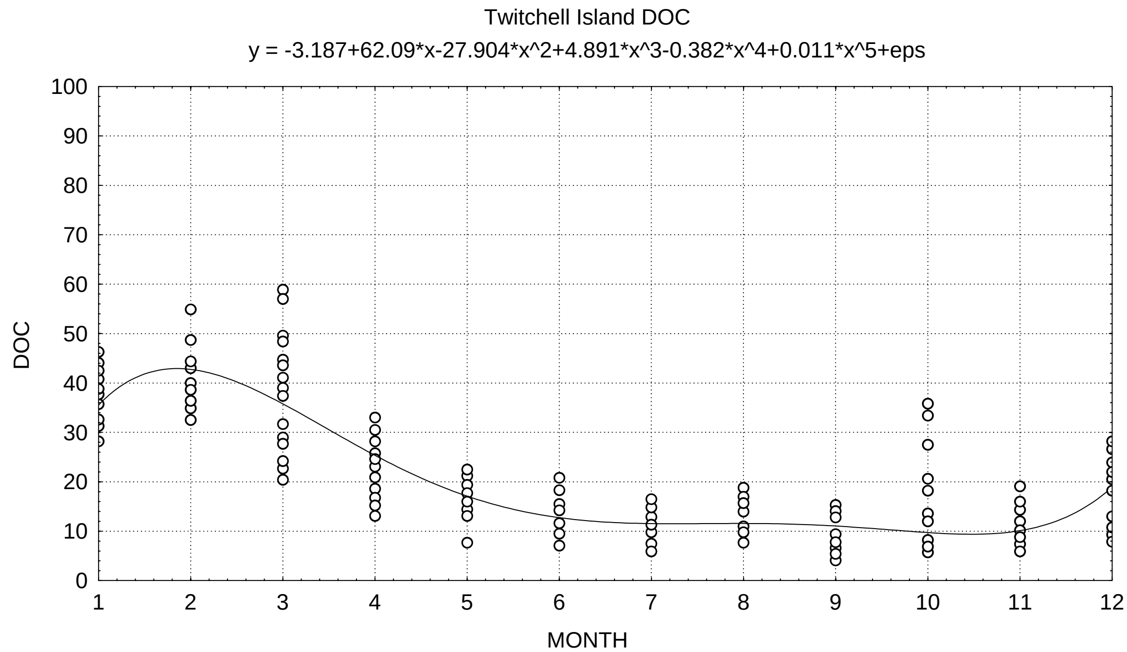
During the Delta Wetlands Project (DWP) EIR/EIS Hearings (October10-12, 2000), the project proponents and their consultants stated that the soils collected from Twitchell Island that were used in the SMARTS experiments were not representative of "average Delta soils" or that on the DWP islands. They claimed that the Twitchell Island soil that was used was higher in soluble EC and organic carbon composition than what occurs on their land. Soil and water quality data of peat soil water (pore water) is limited to a few samples taken from a Jones and Stokes Holland Tract pond experiment and USGS groundwater samples from Twitchell Island. There were no data from the other three DWP islands for comparison to support their statement.

There were, however, agricultural drain water DOC and EC data collected under the DWR MWQI Program at Twitchell Island and the four DWP islands. Two DWP islands that are proposed for conversion to wetland habitat islands are Bouldin Island and Holland Tract. Two other islands, Webb Tract and Bacon Island, are proposed water reservoir islands. If we assume that the DWP islands are similar in characteristics to each other then we might expect similar monthly ranges and patterns in the drain water EC and DOC concentrations. Furthermore, if Twitchell Island soils are much higher in soluble EC and organic carbon components than the DWP islands, then we should also see these differences.

Figures 3.2-1 to 3.2-5 include scatter dot plots and box-and-whisker plots of monthly drainage DOC concentrations at the five islands. The DOC figures showed:

1. Twitchell Island drainage DOC concentrations were more similar to those levels observed at Bouldin Island and Webb Tract than at Holland Tract and Bacon Island.
2. Bouldin Island and Webb Tract drainage DOC levels were consistently much higher (about twice or more) than at Holland Tract and Bacon Island.
3. Bouldin Island drain water DOC concentrations were highest during the wet months (October – April).

Figure 3.2-1.


Twitchell Island DOC
y = -3.187+62.09*x-27.904*x^2+4.891*x^3-0.382*x^4+0.011*x^5+eps
100
90
80
70
60
50
40
30
20
10
0
DOC
1
2
3
4
5
6
7
8
9
10
11
12
MONTH

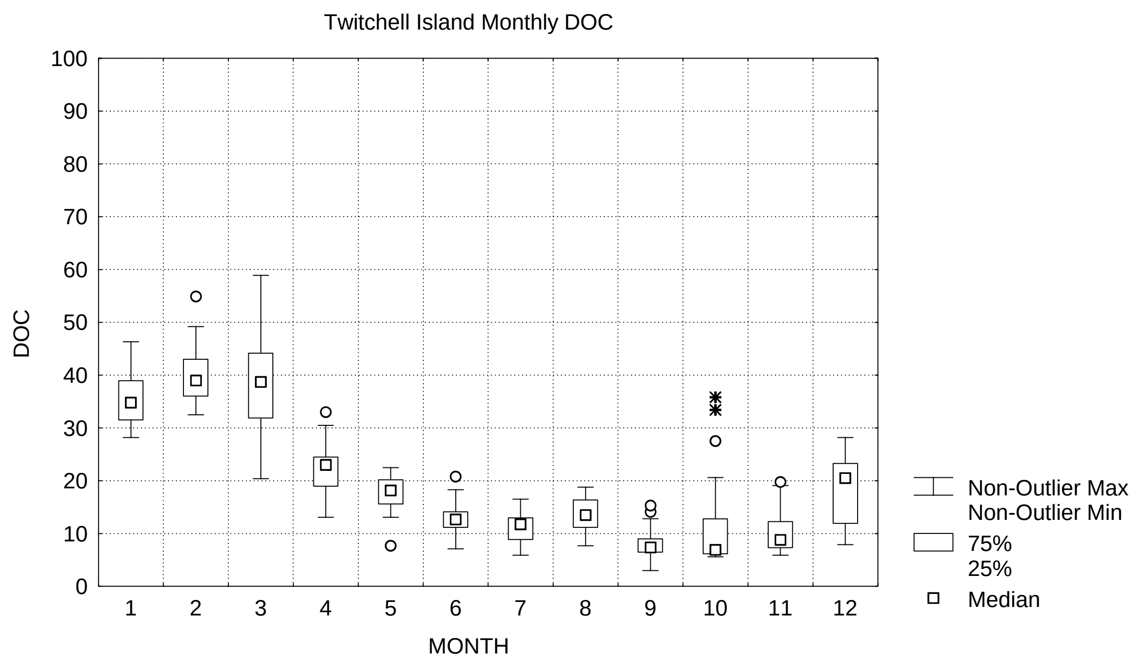
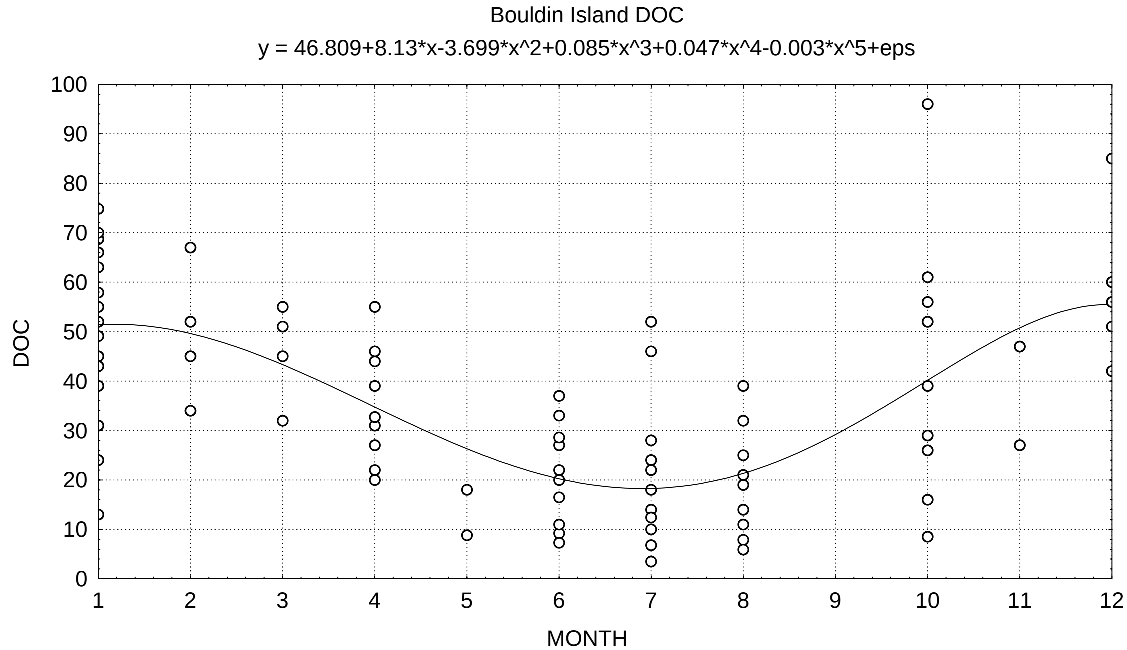

Twitchell Island Monthly DOC
100
90
80
70
60
50
40
30
20
10
0
DOC
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-2.


Bouldin Island DOC
y = 46.809+8.13*x-3.699*x^2+0.085*x^3+0.047*x^4-0.003*x^5+eps
DOC
MONTH
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12

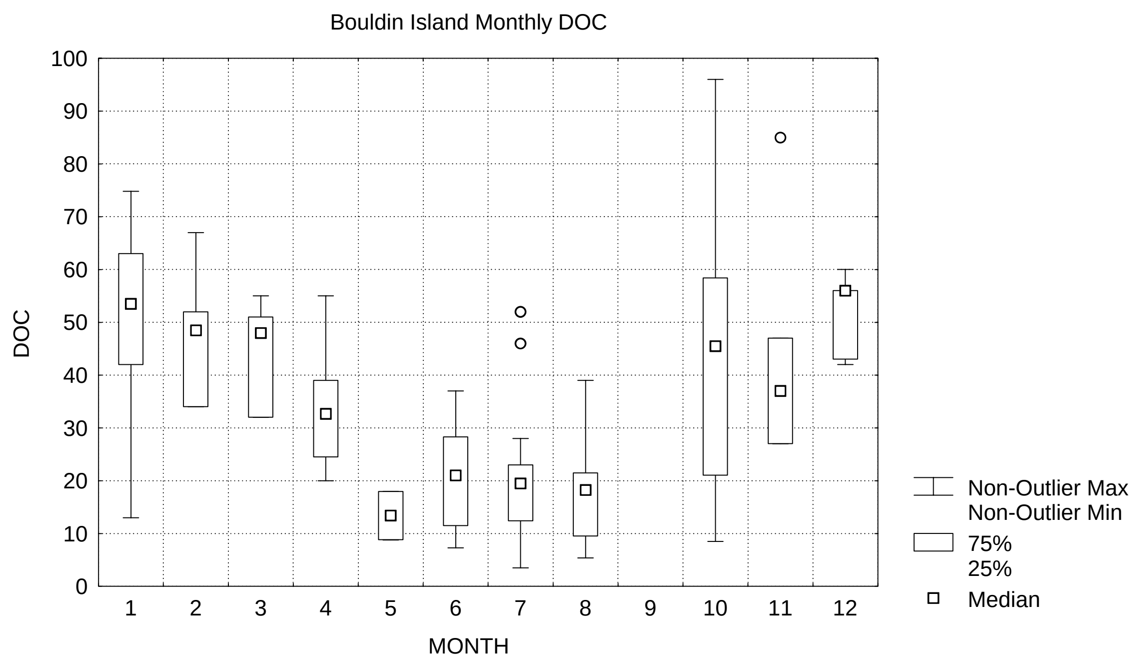
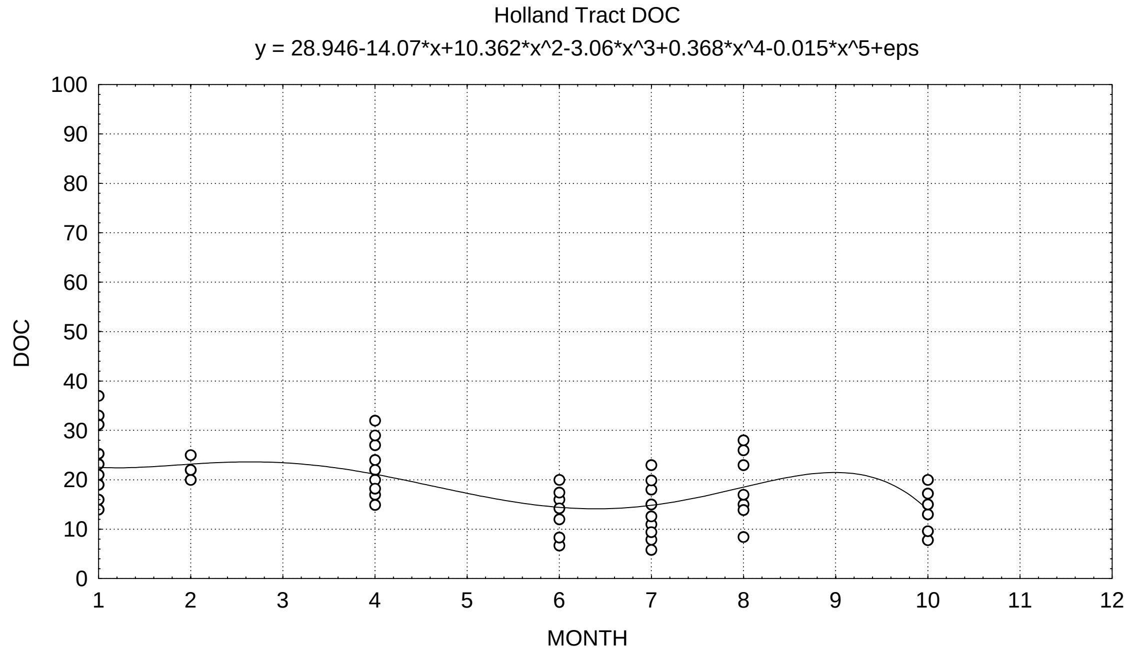

Bouldin Island Monthly DOC
DOC
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-3.


Holland Tract DOC
y = 28.946-14.07*x+10.362*x^2-3.06*x^3+0.368*x^4-0.015*x^5+eps
DOC
MONTH
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12

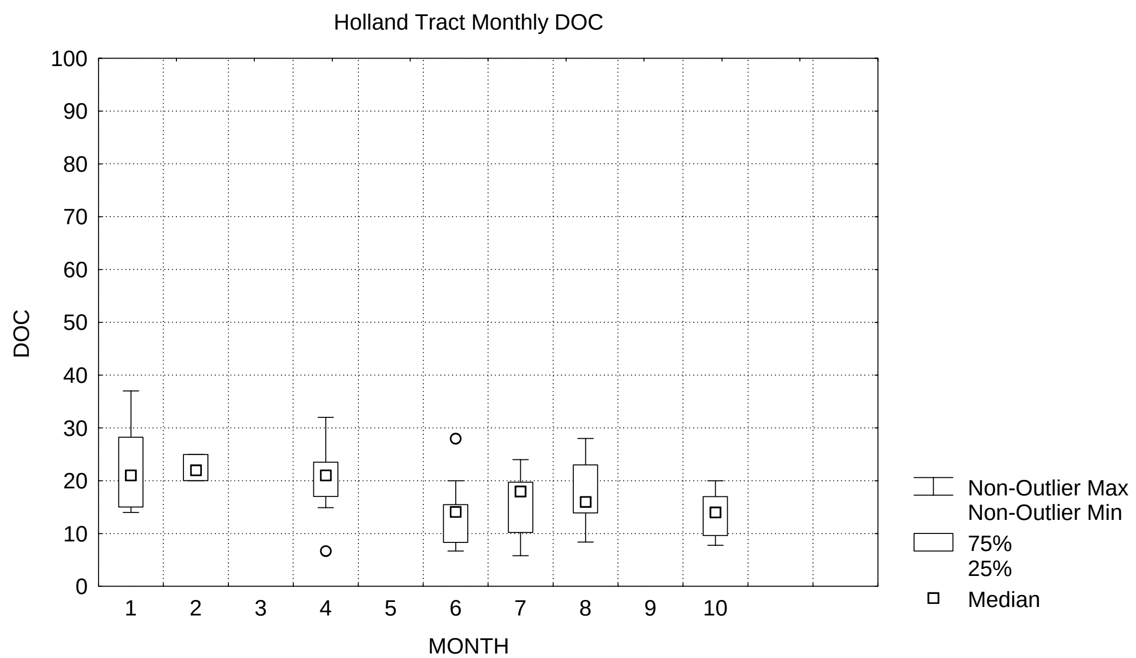
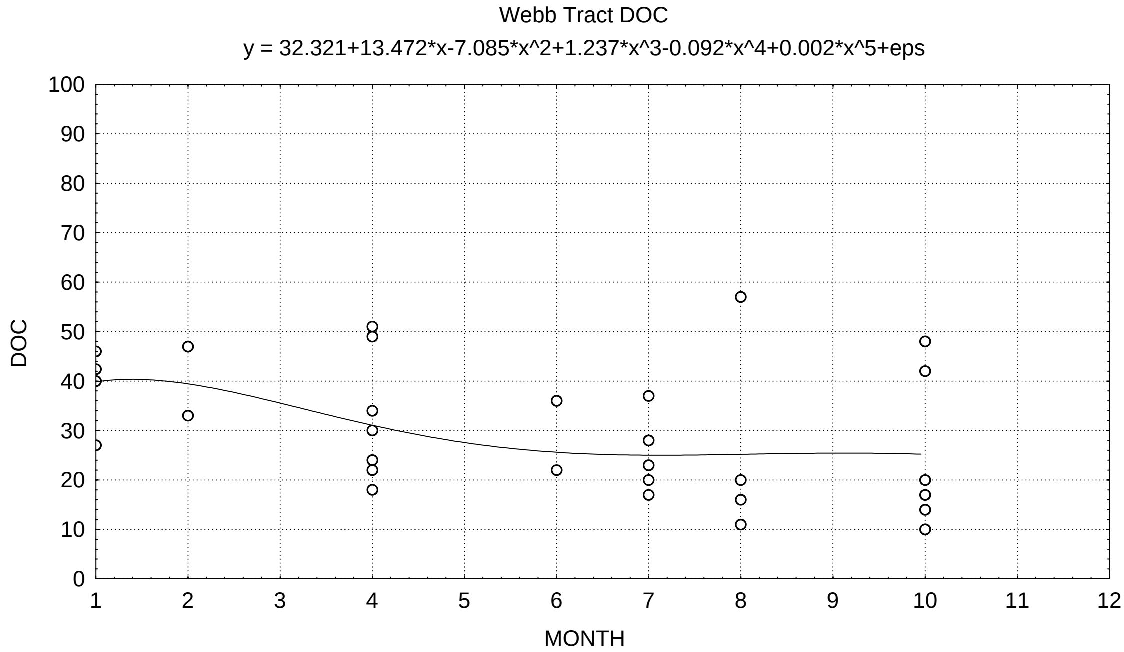
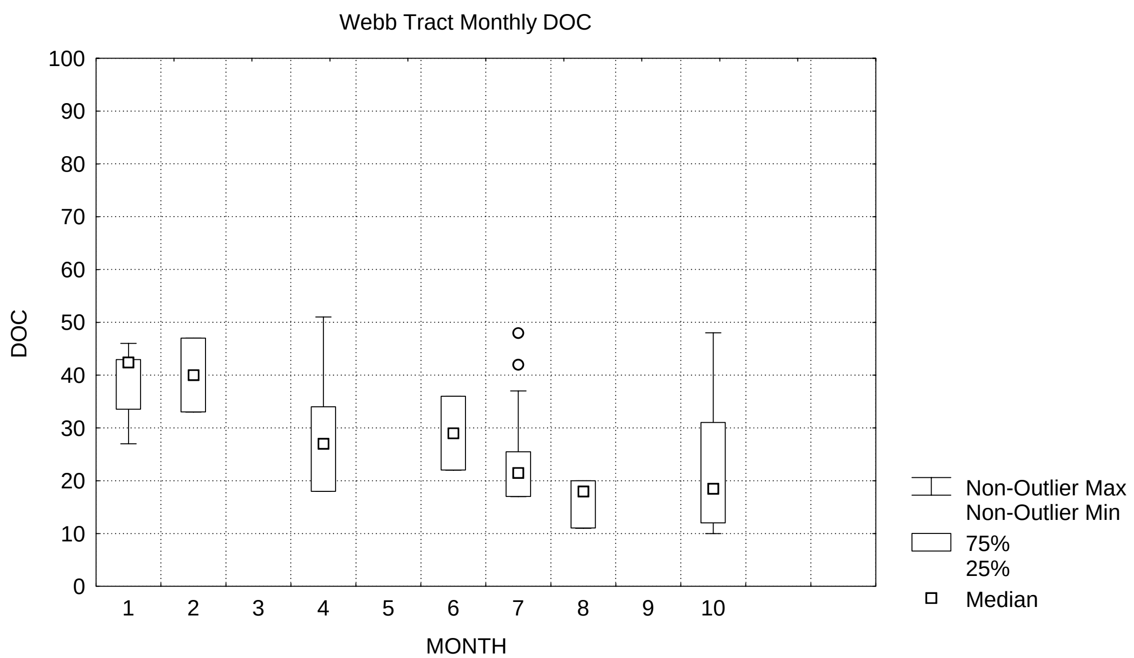

Holland Tract Monthly DOC
DOC
MONTH
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-4.

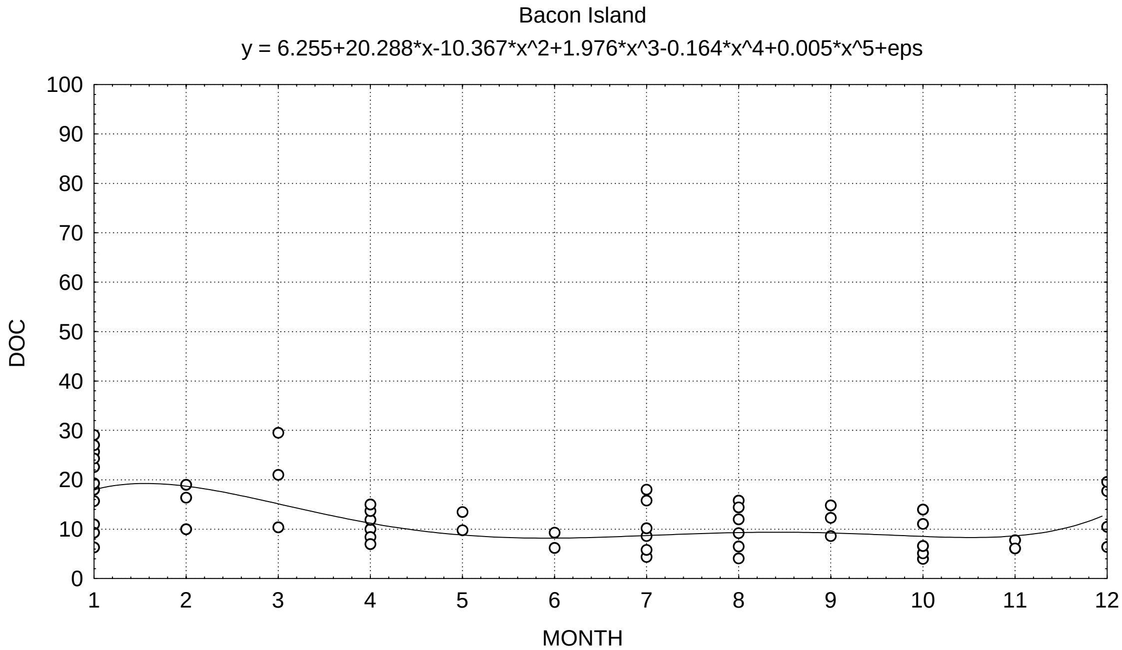


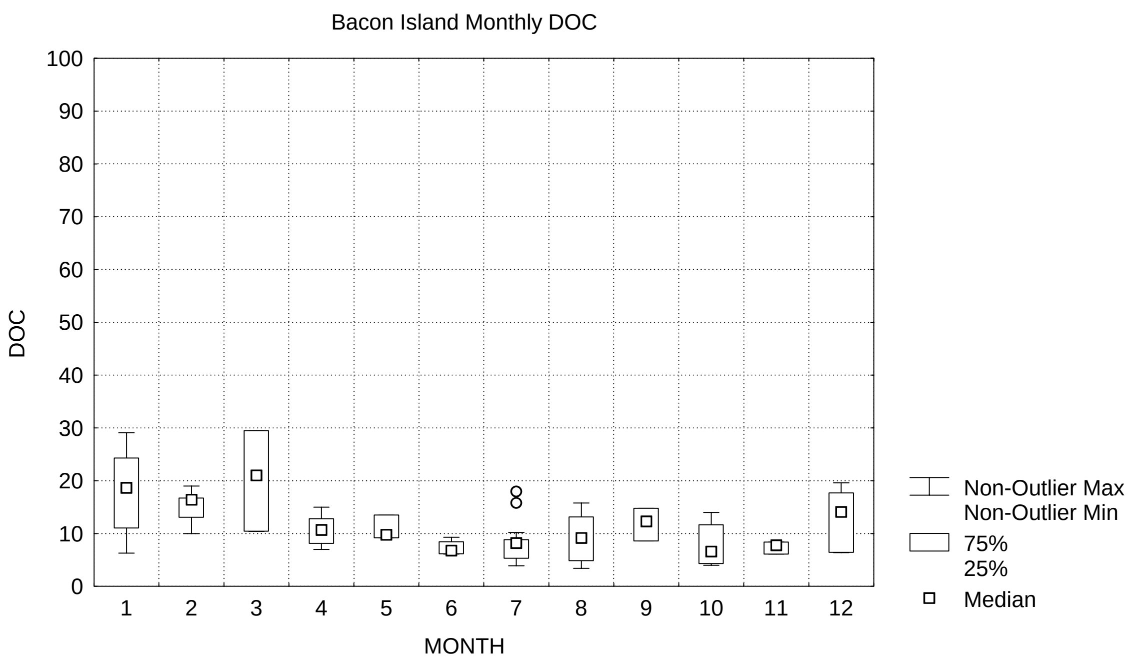
Webb Tract DOC
y = 32.321+13.472*x-7.085*x^2+1.237*x^3-0.092*x^4+0.002*x^5+eps
DOC
MONTH



Webb Tract Monthly DOC
DOC
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-5.


Bacon Island
y = 6.255+20.288*x-10.367*x^2+1.976*x^3-0.164*x^4+0.005*x^5+eps
DOC
MONTH
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12


Bacon Island Monthly DOC
DOC
MONTH
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

These comparisons suggest that at initial water saturated soil conditions DOC concentrations might be higher on Bouldin Island and Webb Tract than on Holland Tract and Bacon Island during the initial diversion. Since the DWP consultants based DOC loading on Holland Tract data, they are likely underestimating loads and the maximum DOC levels that might occur on Bouldin Island and Webb Tract. Based on historical MWQI data, there is no single typical or average Delta island but rather three typical patterns with respect to drainage DOC concentrations and up to four different island drainage EC patterns.

The monthly drainage EC (Figures 3.2-6 to 3.2-10) did not follow the previously described DOC trends. The data showed that:

1. Of the four DWP islands, the lowest drainage EC ranges were at Bouldin Island and Bacon Island. Webb Tract and Holland Tract EC had about two or more higher EC ranges than the other two islands.

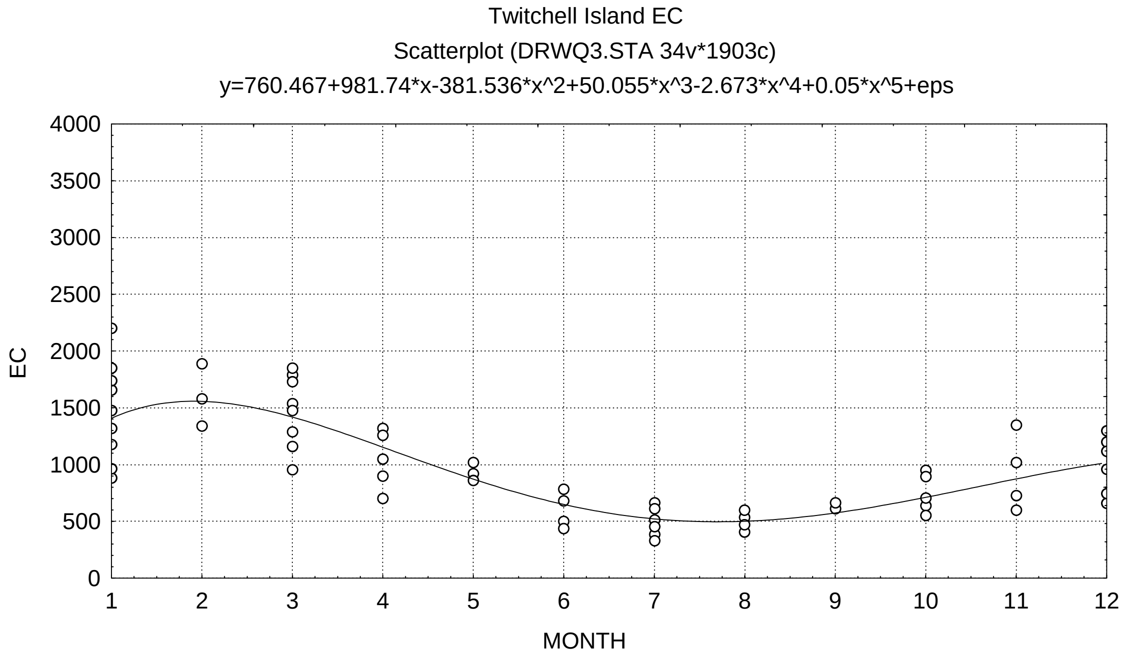
2. The highest EC readings occurred during January through April on Holland Tract and in January and February on Webb Tract.

3. Twitchell Island drain EC was highest in the wet months from October to April. The wet season high EC readings resembled Webb Tract and Holland Tract EC and the dry season low EC readings resembled those observed at Bouldin Island and Bacon Island.

The higher drainage EC values at Webb Tract and Holland Tract than at Bouldin and Bacon islands are attributed to the impact of seawater salts in the irrigation water applied to the islands and seepage under the levees at Webb.

During the first year of operation mineral salt loads from Webb Tract and Holland Tract flooded soils may be higher than from Bouldin and Bacon islands during the DWP diversion period. The differences in monthly EC ranges on the four DWP islands further shows that the use of data from Holland Tract alone is not adequate to represent conditions of all DWP islands.

Figure 3.2-6.


Twitchell Island EC
Scatterplot (DRWQ3.STA 34v*1903c)
y=760.467+981.74*x-381.536*x^2+50.055*x^3-2.673*x^4+0.05*x^5+eps
EC
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH

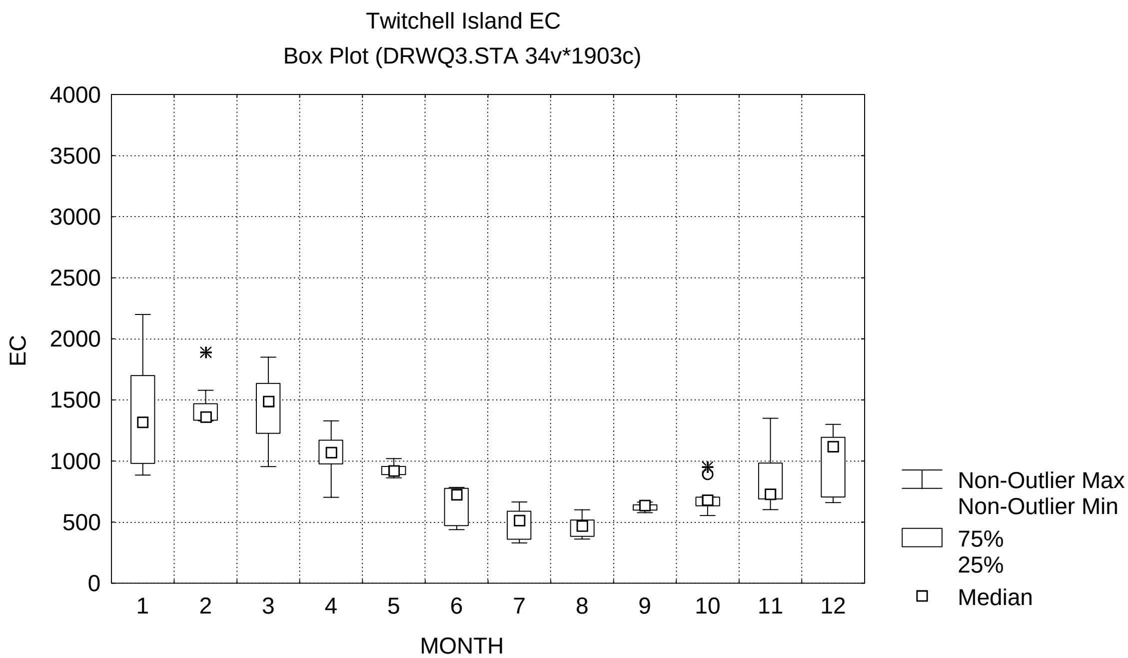
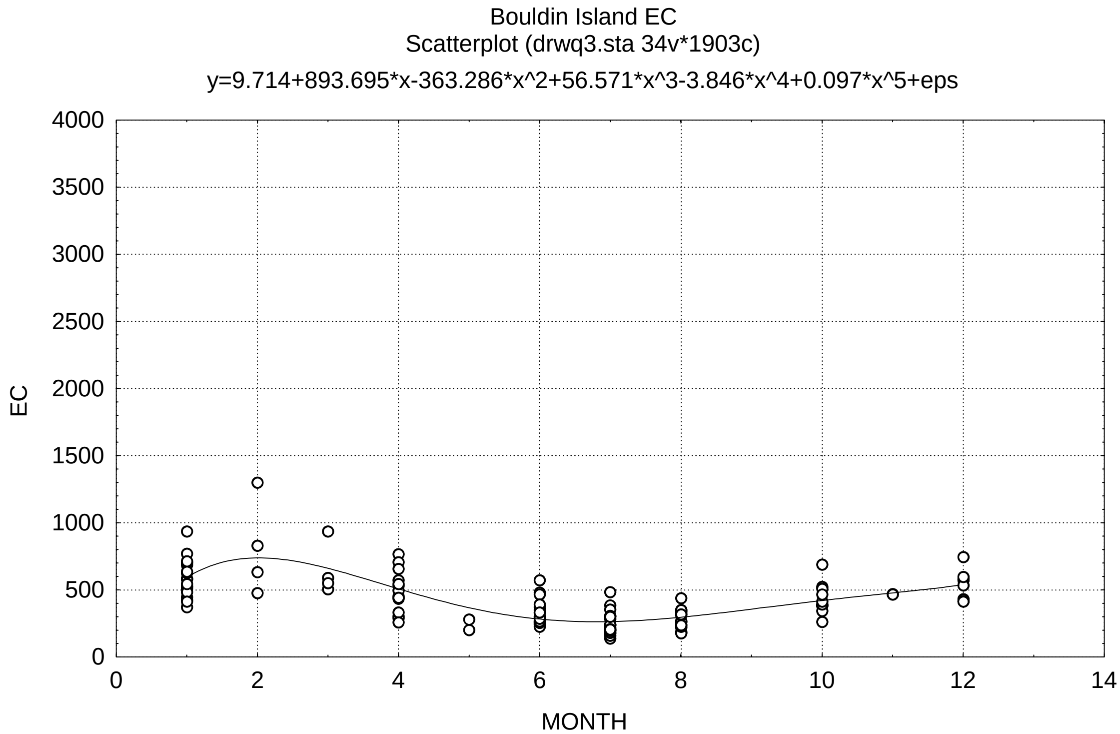
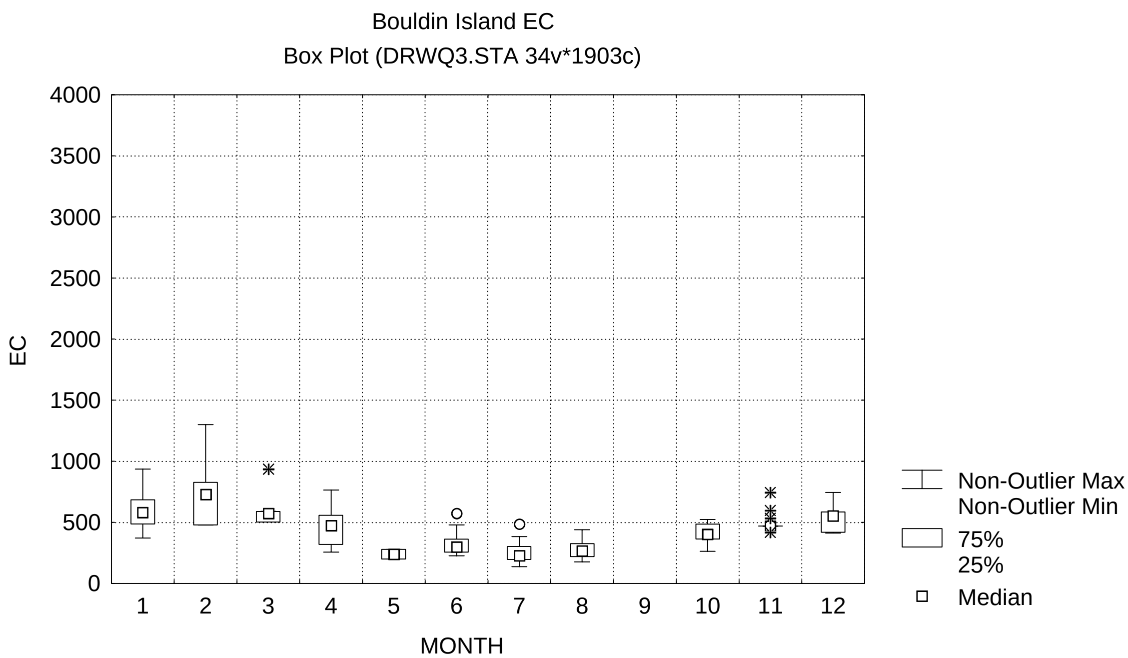

Twitchell Island EC
Box Plot (DRWQ3.STA 34v*1903c)
EC
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-7.

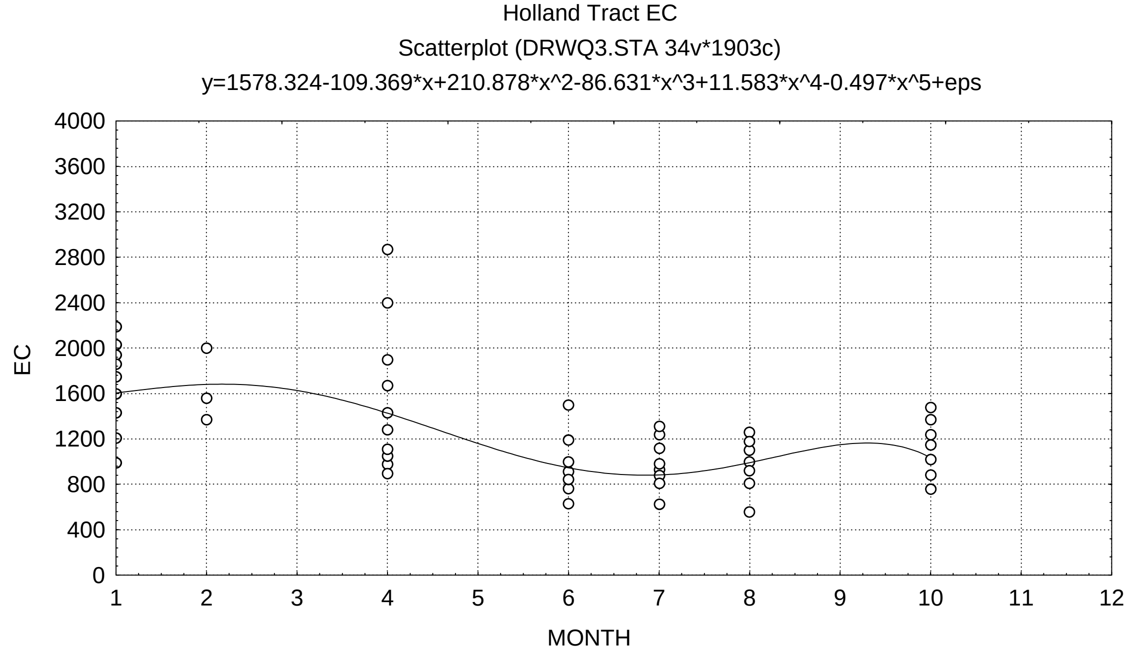


Bouldin Island EC
Scatterplot (drwq3.sta 34v*1903c)
y=9.714+893.695*x-363.286*x^2+56.571*x^3-3.846*x^4+0.097*x^5+eps
EC
MONTH



Bouldin Island EC
Box Plot (DRWQ3.STA 34v*1903c)
EC
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-8.


Holland Tract EC
Scatterplot (DRWQ3.STA 34v*1903c)
y=1578.324-109.369*x+210.878*x^2-86.631*x^3+11.583*x^4-0.497*x^5+eps
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
EC
1
2
3
4
5
6
7
8
9
10
11
12
MONTH

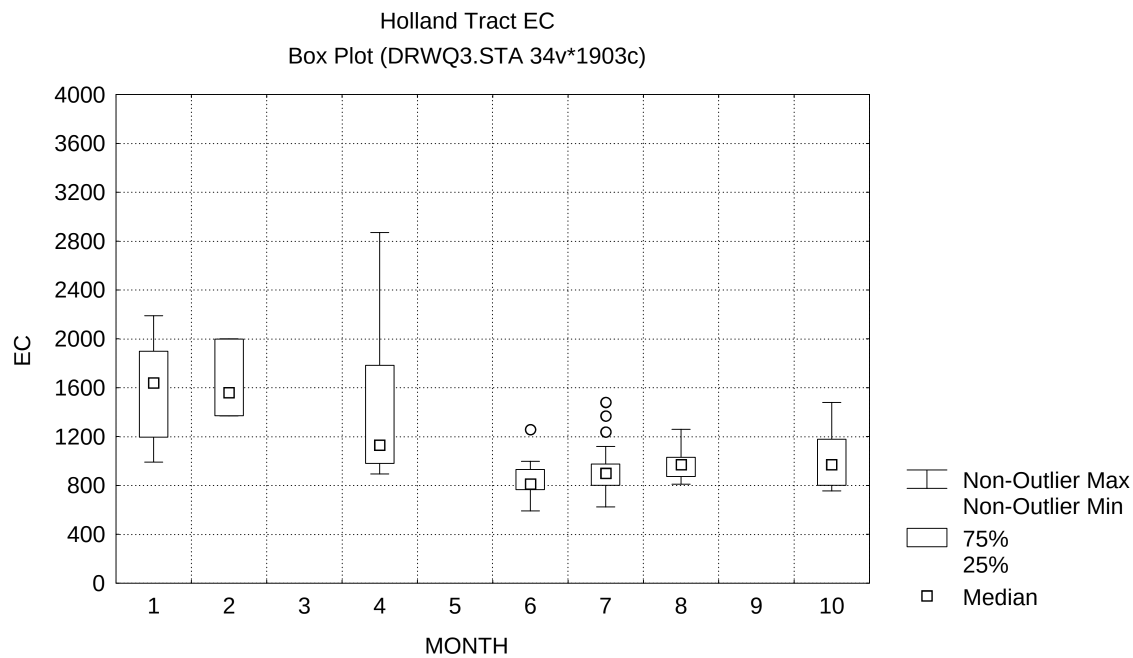
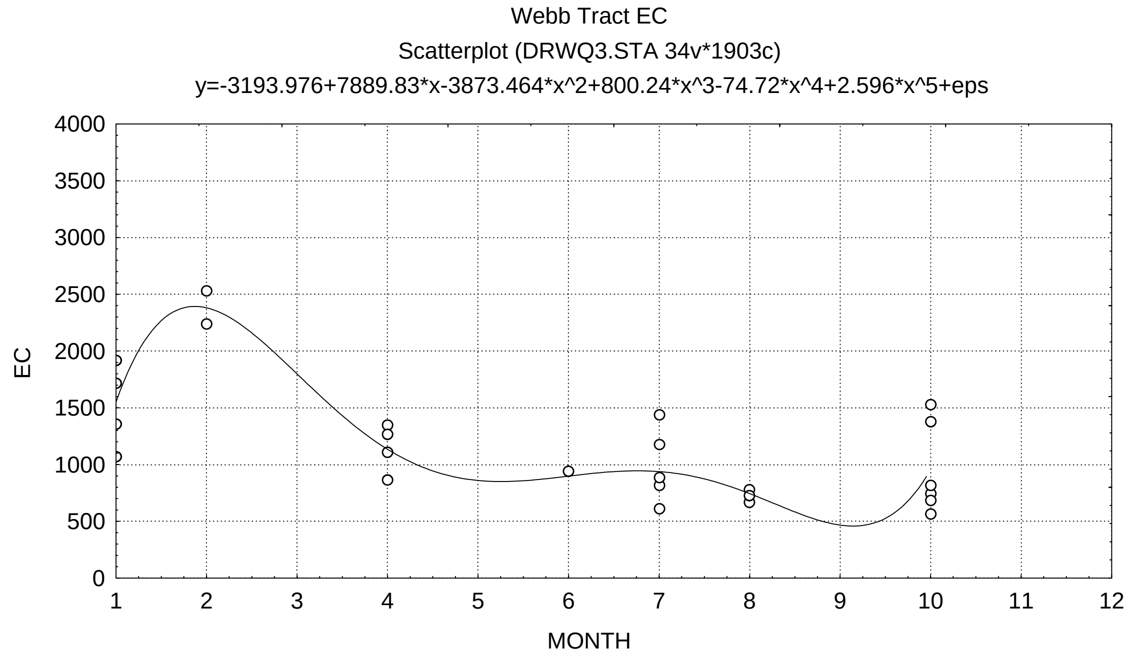

Holland Tract EC
Box Plot (DRWQ3.STA 34v*1903c)
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
EC
1
2
3
4
5
6
7
8
9
10
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-9.


Webb Tract EC
Scatterplot (DRWQ3.STA 34v*1903c)
y=-3193.976+7889.83*x-3873.464*x^2+800.24*x^3-74.72*x^4+2.596*x^5+eps
EC
MONTH
0
500
1000
1500
2000
2500
3000
3500
4000
1
2
3
4
5
6
7
8
9
10
11
12

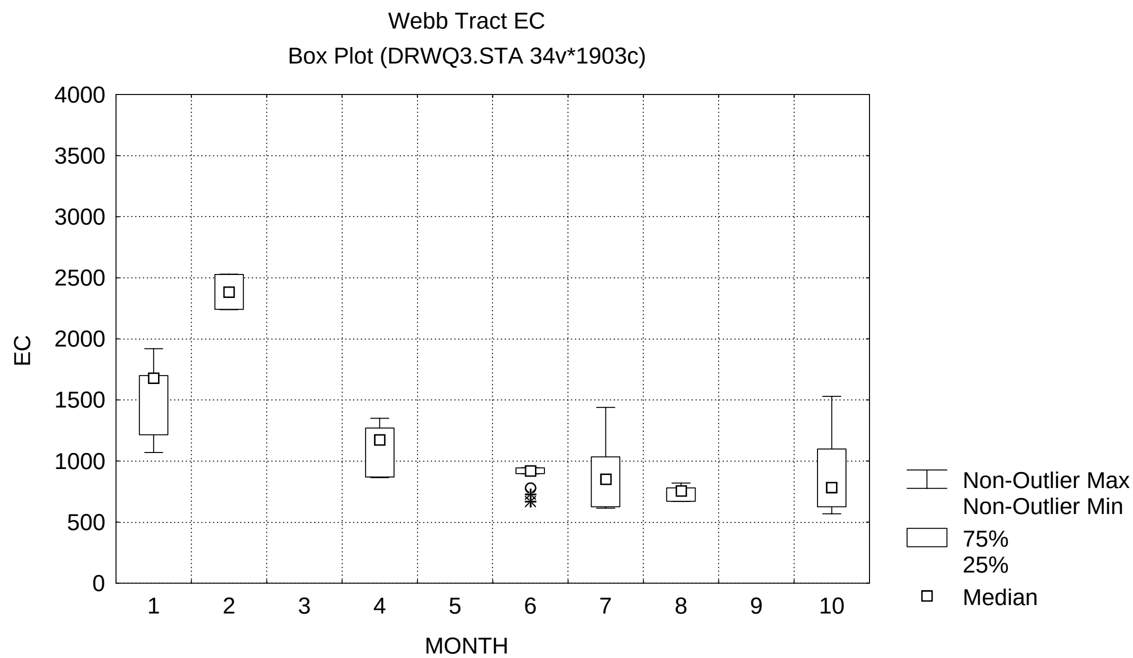
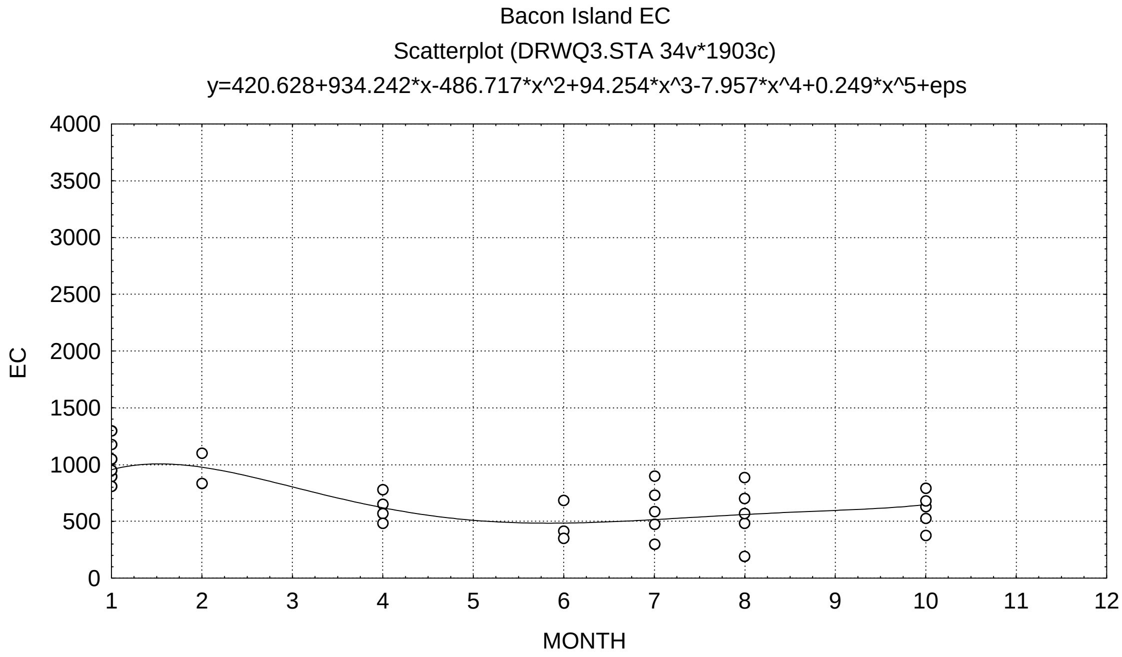
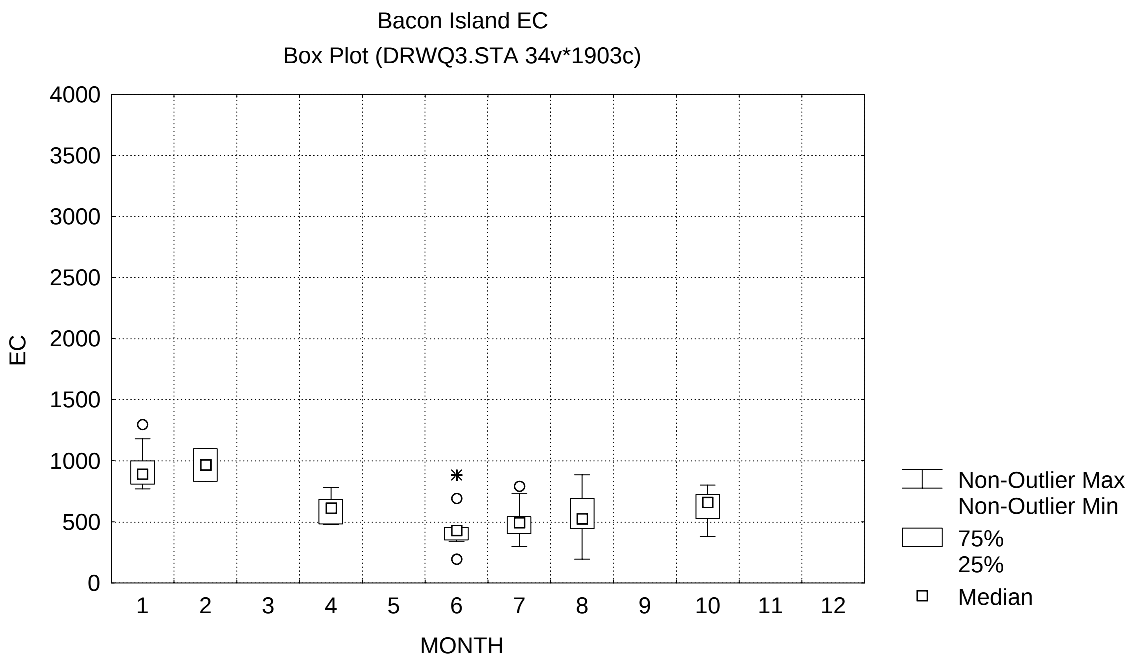

Webb Tract EC
Box Plot (DRWQ3.STA 34v*1903c)
EC
MONTH
0
500
1000
1500
2000
2500
3000
3500
4000
1
2
3
4
5
6
7
8
9
10
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

Figure 3.2-10.


Bacon Island EC
Scatterplot (DRWQ3.STA 34v*1903c)
y=420.628+934.242*x-486.717*x^2+94.254*x^3-7.957*x^4+0.249*x^5+eps
EC
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH


Bacon Island EC
Box Plot (DRWQ3.STA 34v*1903c)
EC
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
Non-Outlier Max
Non-Outlier Min
75%
25%
Median

If winter drainage DOC and EC values indicate the potential availability of DOC and EC from saturated peat soil, we can make inferences about which islands might release more DOC and mineral salts. The following table shows the predicted outcome based on the monthly highest values observed in drainage from the DWP islands during the initial diversion period (January – April).

Table 3.2-1
Hypothesized Initial Shallow Water DOC and EC on DWP Islands

DWP Island – proposed use	Observed peak drainage DOC range /1	Expected DOC values /2	Observed peak drainage EC range /1	Expected EC values /2
Bouldin – habitat	80-50 mg/l	Higher than Holland	1400-800 μS/cm	Lower than Holland
Webb – reservoir	50-40 mg/l	Higher than Bacon	2500-1200 μS/cm	Higher than Bacon
Holland – habitat	40-30 mg/l	Lower than Bouldin	2900-1800 μS/cm	Higher than Bouldin
Bacon – reservoir	30-20 mg/l	Lower than Webb	1300-800 μS/cm	Lower than Webb

1/ Peak drainage values from MWQI during Jan – April months. Highest values typically occur in January and February and decreasing thereafter. Peak wet month drainage DOC at Twitchell Island 35-60 mg/l and EC at 2300-1200 μS/cm. Refer to figures for details.
2/ Hypothesized water quality constituent concentrations relative to comparable island with same proposed use and at initial shallow fill depth of less than 2 feet.

For initial DSM2 modeling purposes, the following annual average DOC and EC values for the DWP habitat islands were recommended:

Table 3.2-2. Recommended Model Habitat Island DOC and EC Values

Habitat Island	DOC (mg/l)	EC (μS/cm)
Bouldin Island	50	750
Holland Tract	40	1100

3.3. Studies of Flooded Peat Soil Environments

DWR SMARTS Experiments

In 1998 - 2000 the MWQI Program conducted experiments on examining how water depth, peat soil, and water exchange, such as in a newly created wetland, could affect drinking water constituents of concern. These experiments were conducted at DWR's SMARTS (Special Multipurpose and Research Technology Station) facility (Jung and Weisser, 1999; Jung and Weisser, 2000). Eight large tanks (810 and 1500-gallon capacities) with different combinations of peat soil depth (1.5 or 4 ft.), water depth (2 or 7 ft.), and water exchange rates (none or 1.5 times per week) were used. The water quality of the impounded surface water and peat soil pore water was monitored. Two separate experiments were run. Experiment #1 was a three-month study (Jung and Weisser, 1999). Experiment #2 was conducted from January 13, 1999 to January 21, 2000. However, samples were collected in June and September 2000 for comparison of changes after the one-year experiment had officially terminated.

Photo 1. SMARTS tanks at DWR Bryte Facility

For comparison the surface and peat water DOC and water temperatures during the course of the study are shown in Figures 3.3-1 and 3.3-2 for the four tanks that had no water exchanges. The test conditions for the four tanks were:

Table 3.3-1. SMARTS Experiment #2 Static Tank Conditions

Tank and initial DOC	Peat soil depth (ft.)	Water depth (ft.)
1 (high initial DOC)	1.5	2
3 (high initial DOC)	4	2
5 (low initial DOC)	4	7
7 (low initial DOC)	1.5	7

The surface water DOC concentrations during the 12 months followed an S-shaped curve. Subsequent samplings at 5 and 8 months after the one-year experiment had ended showed a continued increase in DOC. This indicated continued DOC production that most likely repeated the S-shaped curve pattern. The significant difference in the initial soil pore water DOC concentrations in tanks 1 and 3 from tanks 5 and 7 may be attributed to the soil differences in C:N ratios, soil microbial population, soil enzymes, and carbon quality. The second batch of soil used in tanks 5 and 7 were collected after heavy rains (3.6" November 1998 Sacramento City total). Tanks 1 and 3 peat soil water DOC were 125–160 mg/l during the first 50 days of flooding. Tanks 5 and 7 peat soil water DOC concentrations were 20–33 mg/l during the same time period.

There was a lag period in DOC production during the cool winter (Jan- March) that occurred in the first 50 days when water temperatures were at or less than 10 degrees C. Most of the DOC produced at that time was attributed to leaching (diffusion) of TOC/DOC in peat soil to surface water. Peat soil porosity is typically 50 – 80 percent. During the lag phase, bacteria cell metabolism is directed towards synthesizing enzymes necessary for growth in the medium, in this case, the flooded peat soil medium.

As the weather warmed and water temperature rose above 12 degrees C to about 20 degrees there was a log or exponential growth phase. This occurred at days 50 to about 250 days of flooding (mid-March – August). The exponential phase is the growth period, where bacteria cells undergo binary fission to logarithmically increase the population size. As temperature increases, chemical reactions can proceed at a faster rate. However, there is a limit beyond which some temperature sensitive macromolecules (e.g., protein, nucleic acid, lipid) will be come denatured and therefore nonfunctional. There is also a minimum temperature for growth, below which the lipid membrane is not fluid enough to properly function (Madigan, et. al., 1999). At this stage, there is a steady increase in the growth rate between the minimum and optimum temperature for growth of bacteria, but slightly past the optimum a critical thermolabile cellular event occurs, and the growth rates plunge rapidly as the maximum temperature is approached (Todar, 1997). The decomposition rate of organic carbon can increase by 2 to 4 times when temperature increases by 10 degrees C within the tolerance limits of the organism (Reddy et. al., 1980). This is called the Q10 value.

Figure 3.3-1. Water Temperature and Holding Time on Tanks 1 and 3 DOC Production

The Effects of Water Temperature on DOC Production

SMARTS2 Tanks 1 & 3 Surface and Peat Water

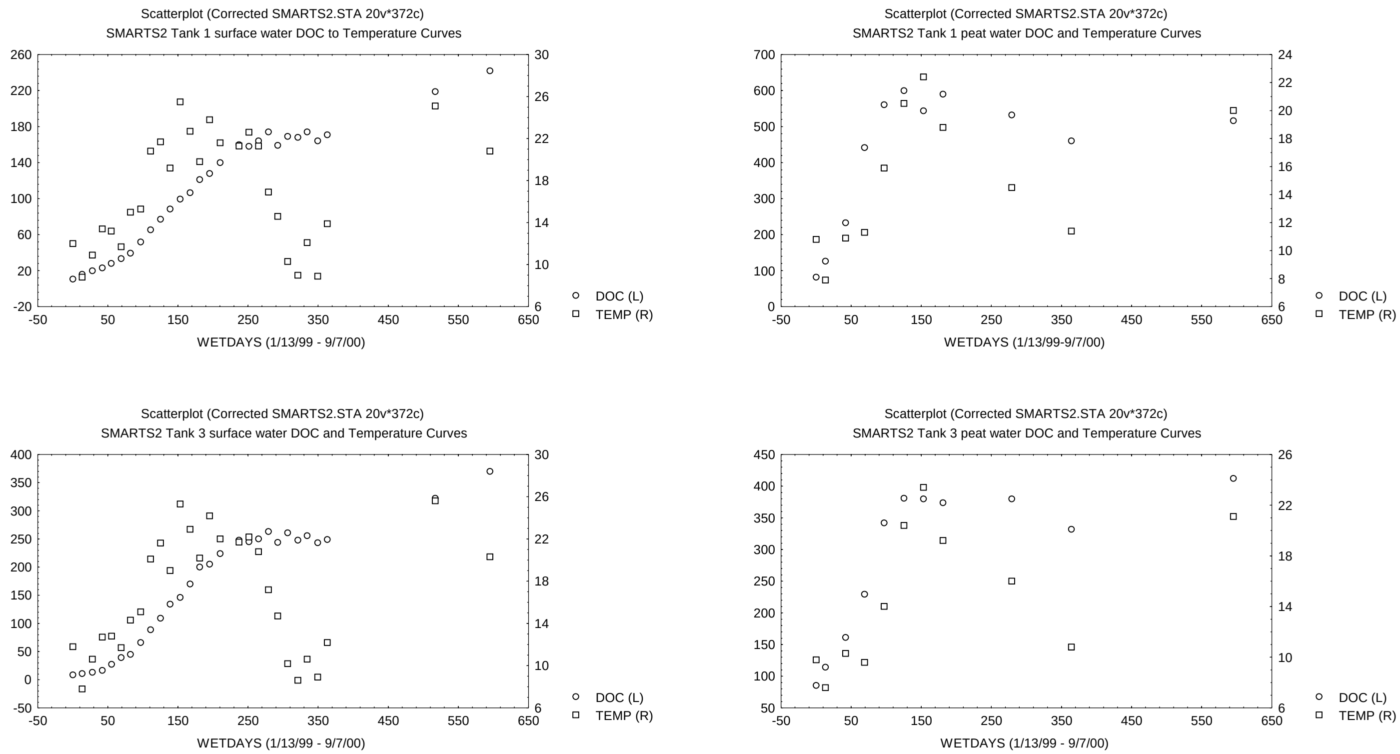
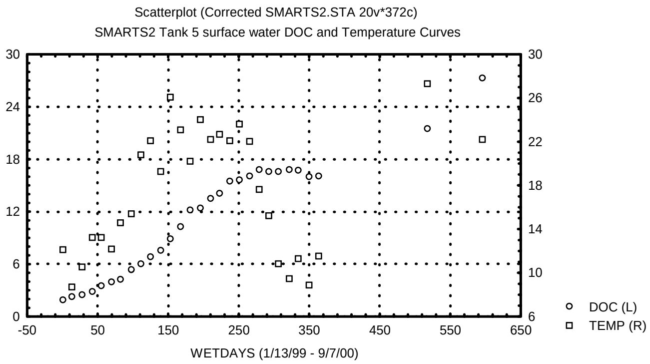
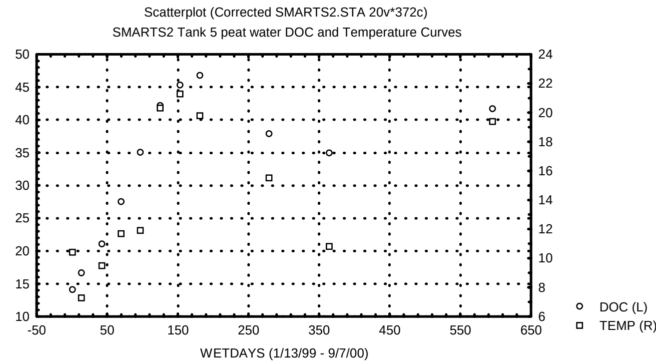


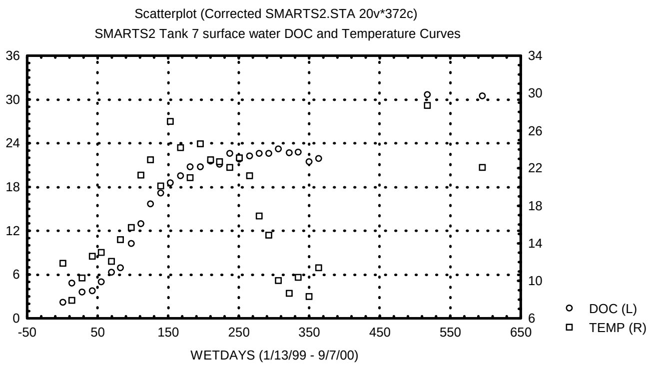
Figure 3.3-2. Water Temperature and Holding Time on Tanks 5 and 7 DOC Production

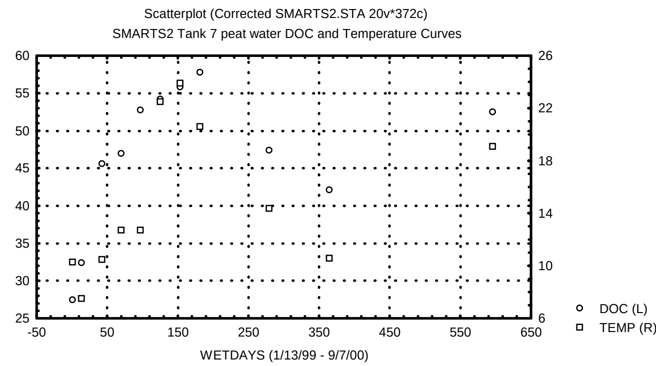
The Effects of Water Temperature on DOC Production

SMARTS2 Tanks 5 & 7 Surface and Peat Water









In a study of estuarine planktonic bacteria, the growth rates ranged from about 3.6 to 6.5 d^{-1} with the higher rates occurring in June bioassays and the lower rates in the December bioassays (Hopkinson, et.al. 1998). Using stable isotopes the researchers concluded that the growth rates were elevated due to dissolved organic matter exchange with bottom sediments. These results suggest that there were gross fluxes of organic matter across the sediment-water interface that were not apparent in the overlying water pool. They further concluded that benthic systems are both sites of inorganic nutrient remineralization in support of planktonic primary producers and sites of dissolved organic matter generation and nutrient remineralization important in support of bacterioplankton production.

There was also a rapid log growth phase in DOC production in the peat soil water in days 50 – 150 as water temperatures rose above 10 degrees C to 20.

The particulate organic carbon is rapidly decomposed and released from the initial leaching of the DOC. This DOC may be labile and susceptible to rapid decomposition to simple organic compounds (e.g., sugars, amino acids, fatty acids). The more complex fraction of DOC such as humic substances will take a longer period of time to degrade from weeks to months compared with hours for the labile simple organic compounds. The specific UV absorbance (UVA-254nm/DOC) or SUVA values support this as initial DOC have a lower SUVA than the more humic organics that have higher SUVA.

At day 150 the rate of DOC production in the surface water began to decline coinciding with the maximum DOC concentration in the peat soil pore water. Peat soil water DOC began to decline after 150 days. The decrease is attributed to declining water temperature, which slowed down microbial degradation of organic matter and diffusion of DOC to the overlying surface water. Samples taken after the one-year experiment showed a repeated increase in DOC production coinciding with the seasonal water temperature cycle.

A stationary phase in surface water DOC production occurred at days 250 to 370 (August – mid-Jan) as water temperatures begin to decline from 22 to 10 degrees C. DOC production by microbial decay had stabilized as the death phase of microorganisms occurred. There was no net significant gain or loss of TOC/DOC during this last period. The samples collected 5 and 8 months after the experiment had ended suggest that the seasonal cycle of DOC production would repeat each year in both the surface and peat soil water. There was no apparent loss of TOC/DOC from the first year and additional new TOC/DOC is produced during the second year but possibly at a much lower rate than the previous year.

Experiment #1 was conducted from July 15, 1998 to October 7, 1998. Results were similar to the second experiment except the growth rate was higher. Starting water temperatures were much greater (17+ degrees vs. 10 degrees C) since the study occurred in the summer. The log growth period extended to the first 70 days of flooding with a stationary phase thereafter. Under these conditions, the results may represent a case where the reservoir islands are dried and refilled in the late summer or fall months for shallow habitat.

The peat soil water DOC production during the first 50 days was likely from microbial decay and leaching in the anaerobic soil. TOC/DOC stabilized or decreased by day 30-50, perhaps indicating the death phase of microbes as lower water temperatures occurred (slower Q10), and/or most of the TOC/DOC had been leached out in Tank 1, which had 1.5 ft. of peat but not in Tank 3 which had 4 ft. of peat.

Delta Wetlands Project Studies

In 1989 DWP consultants conducted a flooded wetland experiment on Holland Tract (Jones and Stokes, 1990; 1993a; 1993b). About 10 of 50 acres of a demonstration wetland were flooded to an average depth of 1 foot in mid-October of 1989. Weekly sampling from November 3, 1989 to January 15, 1990 was conducted to monitor water quality. The TOC/DOC data are shown in Figure 3.3-3. The temperatures from 11/10/89 to 1/15/89 ranged from 5.3 - 14ºC. The TOC concentrations during the three-month study were up to 38.6 mg/l. Due to the short duration of the experiment and the low water temperatures, it is not clear as to whether the TOC concentrations had truly stabilized or would have continued to increase if the experiment was conducted for a longer period. The water temperature was generally below 10ºC during the experiment. Microbial activity is negligible below 5ºC and microbially mediated reduction-oxidation reactions that consume O_2 and reduce Fe and Mn compounds become inhibited (Megonigal et. al., 1980).

The pond was later filled to a depth of about 5 feet in mid-April of 1990 and held until July 25, 1990. Additional siphoning of Delta water was required to maintain the 5-foot water depth due to seepage to nearby drains. TOC concentrations were 29 – 32 mg/l but it is unclear as to what extent the additional water and seepage respectively affected the results by dilution and removal of TOC/DOC. Water temperatures ranged from 19.3 - 26ºC.

The historic maximum monthly drainage DOC concentrations at Holland Tract (Figure 3.2-3) for January – April (wet months) were in about the same range as the pond experiment values (20 – 40 mg/l). If wet months drainage values reflect possible shallow wetland values, Bouldin Island habitat discharges could be over 50 mg/l DOC year-round.

Extracts of water saturated soil samples were also analyzed to provide a relative index of the potential for soil leaching to contribute organic carbon, minerals, and nutrients. Soil samples were collected in late February 1992 with a scoop from the surface and from the bottom of 2-foot deep holes at two locations in the Holland Tract demonstration wetland and from two locations in an adjacent field that had been farmed in 1991. A total of 8 soil samples, 2 from each of the 4 sites were collected. A standard agricultural soil saturated paste method was used. The saturated soil samples were analyzed after 2 hours, 7 days, and 30 days to determine changes with longer saturation times. The holding period test conditions (e.g., redox potential, temperature) were not described. Two laboratories, Anlab and MWDSC, performed the analyses of the extracts. The results are shown in Figures 3.3-5 and 3.3-6. The results illustrated significant variability among the soil extracts between the 2 groups (agricultural field vs. wetland) and within each group, and with holding time. Surface agricultural field samples had DOC concentrations from 110 to 240 mg/l while wetland surface soils had 30 to 70 mg/l DOC. Soils taken from the 2-foot depth had extracted soil water DOC ranging from 40 to 90 mg/l in the agricultural field samples and from 25 to 71 mg/l DOC in the pond soil samples. Some of the wide variability is likely attributed to the heterogeneity and variations in saturation of the soil paste, which make perfect replications or aliquots difficult to obtain. The report indicated that separate soil samples might have been used for each holding period extract. Variations in these samples, such as in lignin and cellulose content, may have led to some of the inconsistent results. Consistency in the results may be improved by using fixed soil to water mixtures (1:2 or 1:5) than saturated paste extracts (Gartley, 2001). There were no data for similar soil extracts from other Delta islands or holding times beyond 30 days.

Figure 3.3-3. Holland Tract Flooded Wetland DOC

Source: Jones and Stokes, 1993b; Figure C3-5

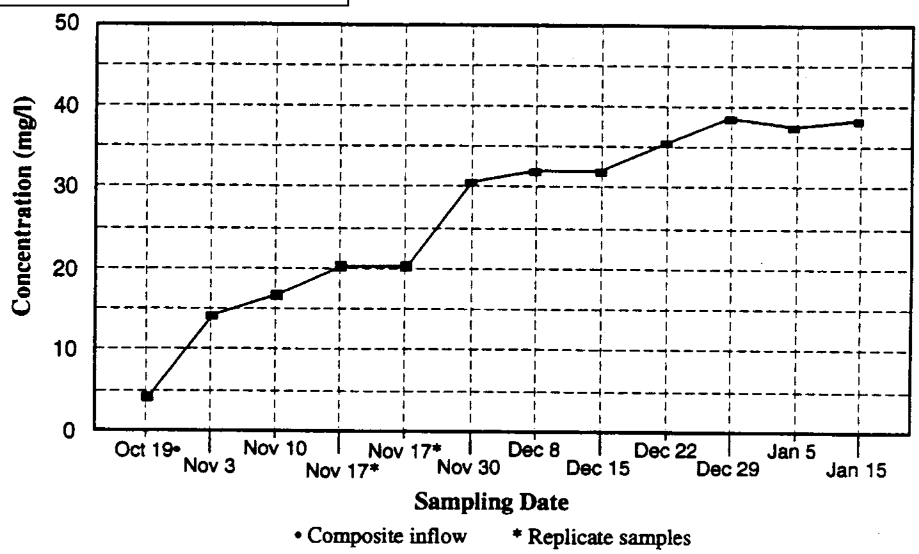
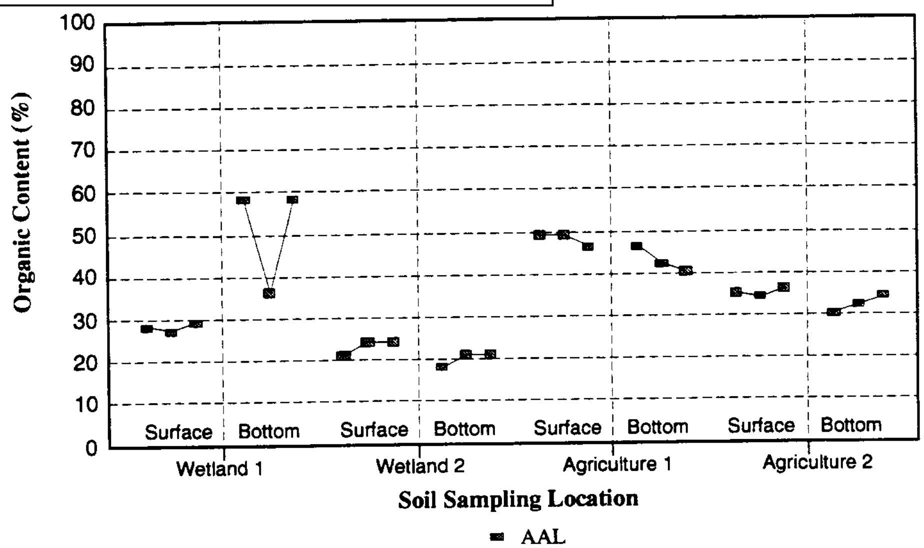
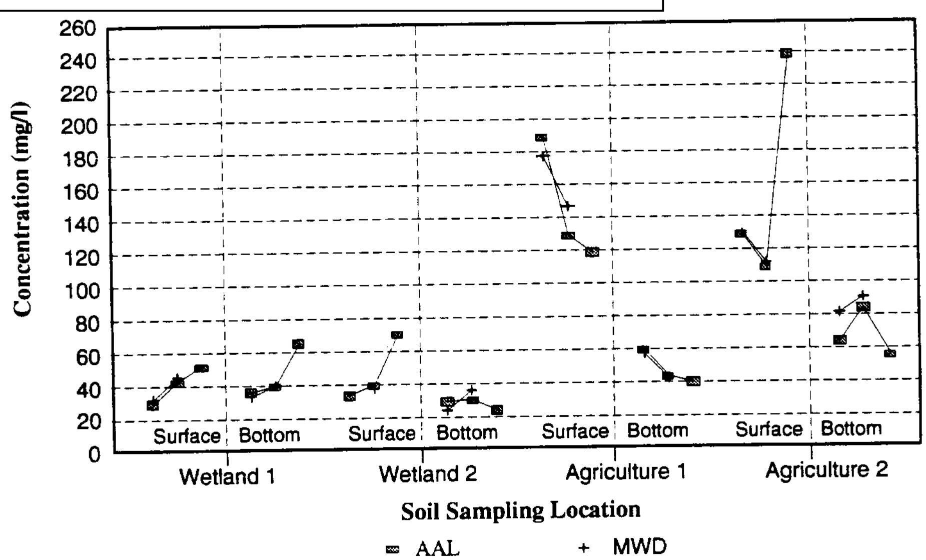


Figure 3.3-4. Holland Tract Soil Extract Organic Carbon

Source: Jones and Stokes, 1993b; Figure C3-22
Paste extract holding times 2 hr., 7 days, and 30 days



Source: Jones and Stokes, 1993b; Figure C3-23
Paste extract holding times 2 hr., 7 days, and 30 days



AAL = Anlab Analytical Lab
MWD = MWDSC lab

Figure 3.3-5. Holland Tract Soil Extracted DOC

USGS Twitchell Island Study

A study to characterize the composition of dissolved organic carbon and trihalomethane formation potentials in water from peat soils on Twitchell Island was conducted by the USGS and cooperatively funded by the MWQI Program (USGS, 1998). Soil water was sampled from near-surface, oxidized, well-decomposed peat soil and deeper, reduced, fibrous peat soil from one agricultural field for over a year. In addition to this study, soil water from three wetland-habitat test ponds was sampled. The wetland test ponds were designed to evaluate the effects of different wetland habitats on land subsidence in the Delta. Lysimeters were installed from 0.5 to 1.5 ft. below land surface and piezometers at the 4.5 to 6.5 ft. depth. The study showed that:

- Organic carbon levels varied. Soil organic carbon concentrations ranged from 18.3 to 27.7 percent carbon for the near-surface soils (0.5 to 1.5 ft. below land surface), from 25.2 to 36.9 percent carbon for soils from 4.5 to 6.0 ft. below land surface, and from 24.3 to 38.6 percent carbon from 6.0 to 7.0 ft. below land surface.

- Groundwater DOC concentrations were highly variable. DOC concentrations in the upper soil zone were highly variable, with median concentrations ranging from 46.4 to 83.2 mg/l. Lower soil zone DOC levels were less variable and generally slightly higher than the upper soil zone, with median concentrations ranging from 49.3 to 82.3 mg/l.

- Soil water DOC fluctuations were related to farming practices and cycles of irrigation and intentional winter flooding. The effects of farming activities to DOC during the study are shown in Figures 3.3-6 and 3.3-7. The soil water DOC concentrations are dependent upon water flux and DOC transport, which were not studied.

Some of the highest DOC concentrations are shown below:

Table 3.3-2. Highest Ground Water DOC Values in USGS Twitchell Island Study

Site	Date	DOC (mg/l)	UVA254nm
TwitLys4	1/02/97	139	
TwitPiz7	6/20/96	207.9	13.340
TwitPiz7	7/17/96	155.6	15.700
TwitPiz7	8/16/96	172.0	11.720
TwitPiz6	11/13/96	132.0, 132.0	8.78, 8.78
Lysimeter 1	10/23/96	121.3 and 119.0	

Source: Tables A3, B1, B4, and F1 (USGS, 1998).

The lysimeters sampled interstitial water from the upper soil zone (0.5 to 1.5 ft. below land surface. Peat soil conditions are usually oxidized, well decomposed, and usually unsaturated in soil moisture except during winter rainfall and flooding and summer irrigation. The increases in DOC reflect soil releases of organic carbon to the aqueous phase during flooding. The wide variability in DOC between sites in September to November was attributed to differences in soil moisture while the fields dried.

Figure 3.3-6. USGS Lysimeter DOC

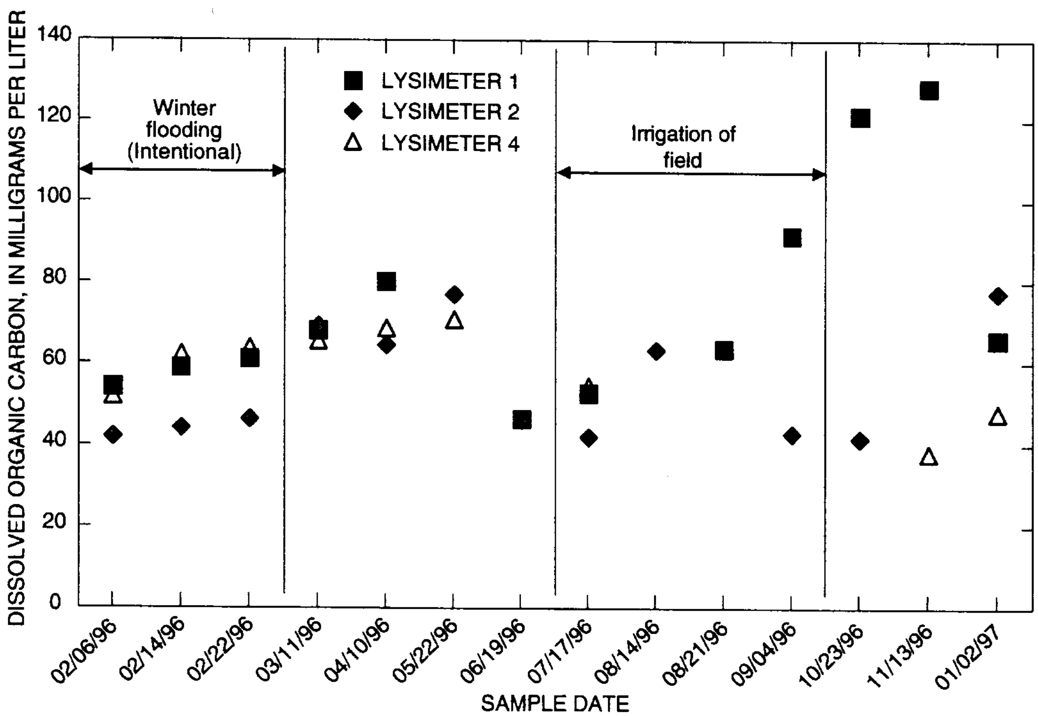


Figure 7. Dissolved organic carbon concentrations for lysimeter samples, February 1996–January 1997, Twitchell Island, California.

The lower soil zone piezometers sampled groundwater from 4.5 to 6.5 ft. below land surface. Anaerobic conditions generally existed at that depth with fluctuated water table heights. Dilution of groundwater DOC from winter flooding and summer irrigation and rapid migration into island drainage canals were evident. The variability in DOC between sites was attributed to changes in soil saturation.

Figure 3.3-7. USGS Piezometer DOC

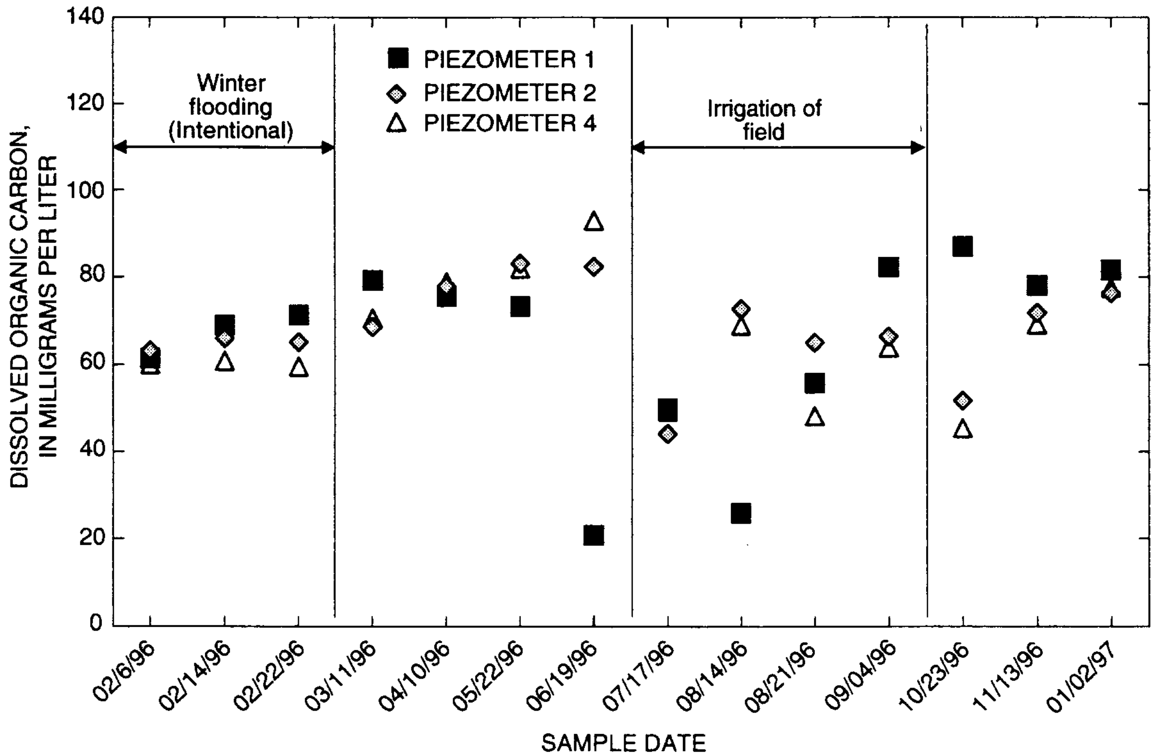


Figure 10. Dissolved organic carbon concentrations for piezometer samples, February 1996–January 1997, Twitchell Island, California

The investigators concluded that during the longer term irrigation period, irrigation cycles cause wetting and drying of soils above the water table thus creating variable conditions for microbial decay of soil organic matter and the release and transport of available organic carbon.

The observed DOC concentrations were less than those observed in the enclosed SMARTS experiments but similar to the Jones and Stokes saturated soil paste values held for 30 days. In the SMARTS study, the soil was mixed and the soil water was confined without drainage during the experiment (3 months in Experiment #1 and 20 months in Experiment #2). Under the agricultural field and wetland conditions on Twitchell Island, drainage and subsurface water movement (horizontal and vertical) was occurring thereby reducing the soil-to-water contact time. It is not known if under a filled reservoir operation if the seepage or pore-water quality would resemble the high DOC concentrations seen in the field or SMARTS tanks.

Other Studies

In 1995, the South Florida Water Management Water District, the U.S. Environmental Protection Agency, and the USGS studied the surface water chemistry of canals and wetland areas in South Florida (USGS, 1995). The DOC and specific UV absorbance of water samples from 10 locations are presented in Table 3.3-3. Surface water and marsh pore-water samples were collected and analyzed. The surface water samples were collected at a single depth from 7 sites and at two depths from 3 locations. Marsh pore-water samples were collected at several depths below the sediment water interface at 4 locations. Surface water samples were collected at each pore-water sampling locations.

Table 3.3-3. South Florida Wetlands DOC and SUVA

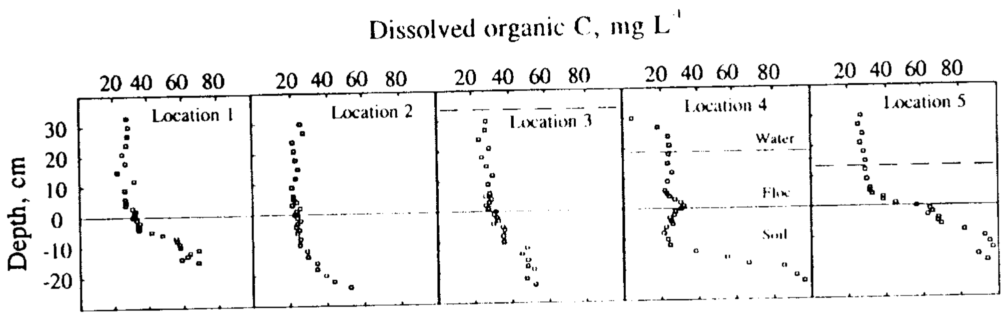
Site ID	Site name	Depth (m)	Water type	DOC (mg/L)	SUVA[/1]
F1-0CM	F1 @ 0 cm	0	pore-water	32.6	0.033
F1-10CM	F1 @ 10 cm	0.1	pore-water	72.5	0.035
F1-20CM	F1 @ 20 cm	0.2	pore-water	111.6	0.035
F1-30CM	F1 @ 30 cm	0.3	pore-water	135.6	0.032
F1-74CM	F1 @ 74 cm	0.74	pore-water	132.5	0.029
F4-0CM	F4 @ surface	0	surface	36.5	0.032
F4-5CM	F4 @ 5cm	0.05	pore-water	51.8	0.038
F4-10CM	F4 @ 10cm	0.1	pore-water	55	0.035
F4-20CM	F4 @ 20cm	0.2	pore-water	57	0.036
F4-30CM	F4 @ 30 cm	0.3	pore-water	63.1	0.032
F4-40CM	F4 @ 40cm	0.4	pore-water	63.2	0.033
U2	U2 @ surface	0	surface	38.4	0.033
U3-0CM	U3 @ 0cm	0	pore-water	36.5	0.031
U3-5CM	U3 @ 5cm	0.05	pore-water	45.9	0.036
U3-10CM	U3 @ 10cm	0.1	pore-water	43.3	0.037
U3-20CM	U3 @ 20cm	0.2	pore-water	49.2	0.036
U3-30CM	U3 @ 30cm	0.3	pore-water	65.6	0.033
U3-40CM	U3 @ 40cm	0.4	pore-water	58.7	0.034
F0-1M	F0 @ 1m	1	surface	37.6	0.034
F0-2.5M	F0 @ 2.5m	2.5	surface	36.3	0.035
E0-1M	E0 @ 1m	1	surface	38.4	0.034
E0-3M	E0 @ 3m	3	surface	37.5	0.034
S10D-1M	S10D @ 1m	1	surface	39	0.033
S10D-1MD	S10D @ 1m-dup	1	surface	38.3	0.034
S10D-2M	S10D @ 2m	2	surface	38.7	0.003
S10E-1M	S10E @ 1m	1	surface	27.3	0.03
L67-S333	L67 @ S333	0	surface	23.5	0.027
L67-S151	L67 @ S151	0	surface	23.3	0.03

Surface water samples taken at depths 0, 1, 2, 2.5, and 3 meters. Pore-water samples taken at centimeter (cm) depths below interface.
/1 SUVA computed as (UVA/DOC) not (UVA/DOC)100.

The DOC data showed that pore-water DOC concentrations increased with sediment depth. Overlying surface water DOC concentrations were nearly 40 mg/l. SUVA values were similar to those seen in Sacramento-San Joaquin Delta agricultural drainage and channels.

A recently constructed marsh that was converted from previously drained agricultural land in Lake Apopka, Florida also showed increasing DOC concentrations with peat soil depth (D'Angelo and Reddy, 1994). Water depth of this marsh was maintained at 35 to 75 cm and the water retention time was 3 to 12 days. The study followed changes in the temporal and spatial distribution of selected nutrients during the first 13 months of operation. Figure 3.3-8 shows the DOC distribution in the shallow water column and peat soil layer at five marsh sites. The vertical distribution of DOC after 13 months ranged between 19 and 97 mg/l, with the higher values in the peat soil. The highest DOC concentrations were found at Locations 4 and 5 (1500 and 3000 m from the inlet), at soil depths > 12 cm. During the 13 months, a floc layer accumulated at the soil-water interface. Anaerobic conditions in both the floc sediment and peat soil layers had significant effects on nutrient retention and release in the soil-water column. Water column DOC averaged about 25 mg/l.

Figure 3.3-8. Lake Apopka Wetland DOC



3.4. Conceptual Model for IDS Reservoir Water Quality

The water quality model for organic carbon production in the reservoir islands of the Delta Wetlands Project should address three major components as illustrated in Figure 3.4-1. They are:

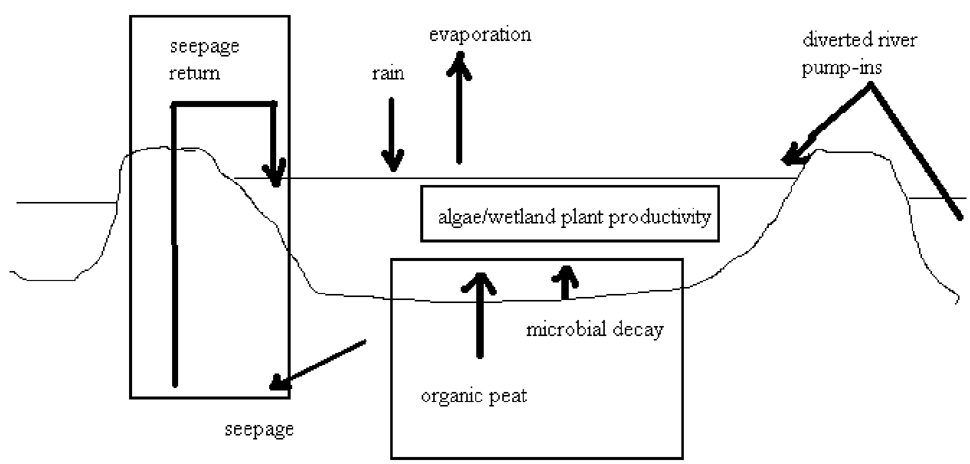
1. A peat soil DOC release and generation component that predicts the reservoir water organic carbon concentrations from leaching and microbial decay of peat.

2. A seepage return water component that predicts the amount and concentrations of organic carbon that is captured and cycled back into the reservoir from seepage pumps located along the perimeter of the reservoir island levees.

3. An algae and wetland plant production compartment that predicts the contribution of organic carbon from primary productivity in the reservoir.

This report describes the algorithms of the first two components. The third component is being developed under contract to ERA (Ecological Research Associates, Davis, CA).

Organic Carbon Sources and Concentration Factors for In-Delta Storage Reservoir Model



Peat Soil DOC Release and Generation Module

The Peat Soil DOC Release and Generation component addresses organic carbon released from the flooded peat soil and its breakdown by microbial communities in the soil, the soil-water interface, and in the water column over time. The DWR Delta Modeling Section requested an examination and development of mathematical relationships for DOC with possible explanatory variables, which included diversion quality, residence time, season, water level, and soil characteristics. The planned operations of the reservoir islands include filling in the winter months when water is available for diversion onto the islands and releasing water in summer when water is in demand.

The only study available to develop an algorithm for water storage on a Delta peat soil island was from the SMARTS Experiment #2. There are no projects or case studies similar to the DWP reservoir islands.

The SMARTS Experiment #2 showed that TOC/DOC production over time (days flooded) in both the surface water and peat soil pore water followed a logistic equation. Procedures for solving the equation are described in calculus and engineering texts (Coughlin and Zitarelli, 1989; Lial et. Al., 1993; Fair et. Al, 1958). The general equation of the logistics curves for DOC that were seen in the experiment is:

$$\mathbf{f(t) = \frac{A}{1 + B e^{-kt}}}$$

where f(t) represents the DOC concentration in mg/l at time t, A represents the maximum DOC concentration in mg/l, k is the growth rate in days^{-1}, and t is the time in number of water storage duration in days. B is a coefficient that is calculated from the starting DOC concentration. The maximum rate of increase is the maximum of the derivative of the logistic equation, y = f(t). It occurs at the point of inflection of f(t).

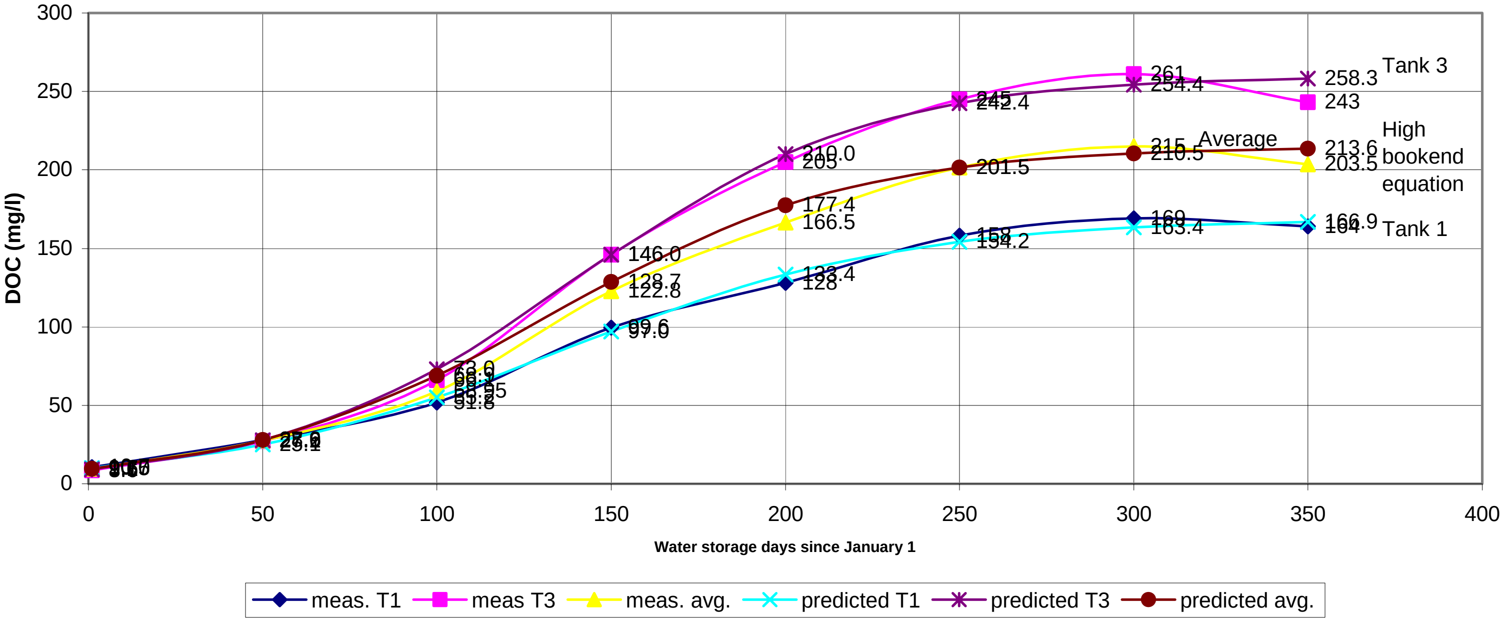
The SMARTS Experiment #2 study period simulated initial flooding of peat soil beginning in January and held for 20 months. The study period overlapped and extended past the planned operations schedule of the DWP reservoir.

In the SMARTS Experiment #1 trial study, the study period was three months (mid-July – early October). The Experiment #1 DOC concentrations over time also fitted a logistics curve but with higher growth constant (k). This was attributed to the much warmer summer temperatures, which accelerated microbial decay and TOC/DOC release and production rates.

A graph showing the predicted maximum DOC concentration over a 360 day water holding period for the predicted logistics equation, measured values in SMARTS Experiment #2 tanks 1 and 3, and the average of the measurements are shown in Figure 3.4-2. This figure shows the results of submerging peat soil for a year in two feet of water. The Y-axis represents the DOC concentration and the x-axis represent the water storage days since filling a tank to a two-foot water depth over a peat soil layer of 1.5 and 4 feet in thickness. The dilution water (city tap water) had a DOC of 1 mg/l. The data was collected semi-monthly for a year. The start of the experiment coincided with the major filling period of the proposed Delta Wetlands Project, which is in the winter, December – February. Water was held for over a year to simulate long-term storage.

Figure 3.4-2. Shallow Tank Measured and Predicted DOC Concentrations

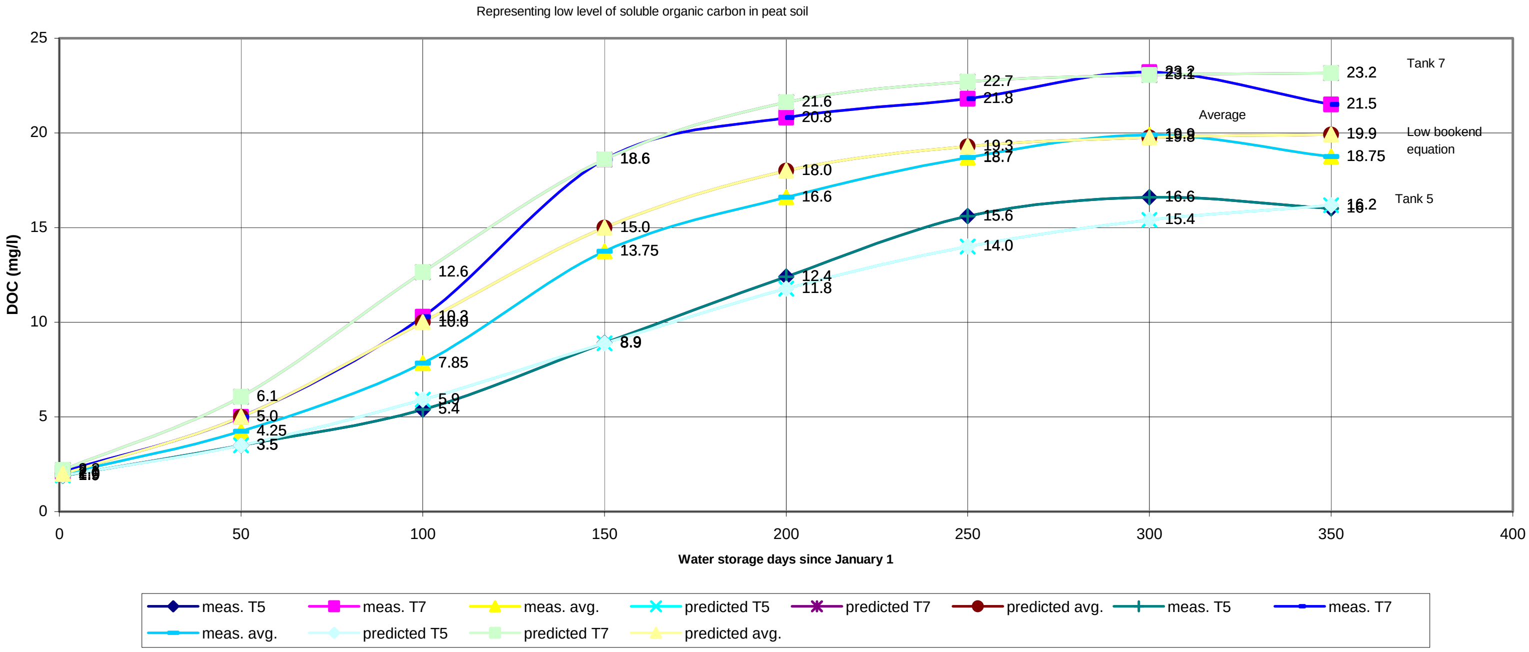
Representing high level of soluble organic carbon in peat soil



On the basis of the good fit of the observed DOC concentrations and the logistics equation, an algorithm for estimating DOC from the processes of peat soil leaching and microbial decay of peat soil was developed. The logistics equation that represented the average DOC values of tanks 1 and 3 was selected to represent the high bookend equation or value for the model. This equation represented predicted DOC concentrations in reservoir water from flooded soils with high DOC.

A logistics curve for DOC concentration was also seen in tanks 5 and 7 (Figure 3.4-3). These two tanks held 7 feet of water but contained soil with much lower organic matter. A rainstorm had leached and drained away much of the soil organic matter prior to when the soil was collected for these tanks. The loss of organic matter and being filled to 7 feet not 2 feet of water as in tanks1 and 3 accounted for the lower maximum values that were reached (the A variable). The logistics equation that represented the average DOC values of tanks 5 and 7 was selected to represent the low bookend equation or value. This equation represented predicted DOC concentrations in reservoir water from flooded soils with low DOC.

Figure 3.4-3. Deep Tank Measured and Predicted DOC Concentrations



The high and low bookend equations are shown in Table 3.4-1. Appropriate dilution factors to represent a filled island reservoir (average water depth of 21 feet) will need to be applied to each bookend logistics equation as tanks 1 and 3 were flooded to a 2-foot depth while tanks 5 and 7 were flooded to 7-feet.

Table 3.4-1. Bookend Logistics Equations for Model Algorithm

Bookend Condition	Logistic Equation DOC (mg/l) = $A/(1+Be^{-kt})$
Low DOC soil @ 7 ft. water depth	$20/(1+9e^{-0.022t})$
High DOC soil @ 2 ft. water depth	$215/(1+21.22e^{-0.022t})$

To compute DOC at time (t) for a 21-foot deep reservoir using Figure 3.4-2, we would divide the value at f(t) by 10.5 (i.e., 21'/2') and add the dilution water DOC concentration. For example, using the high bookend curve for day 200 in Figure 3.4-2, the predicted DOC is 177.4 mg/l for a 2-foot deep reservoir. Diluting this value by 10.5 gives an estimated DOC of 16.9 mg/l in a 21-foot deep reservoir. When the diverted river water DOC concentration, which can range from 4 to 6 mg/l, is added to the computation, the predicted reservoir water DOC can be over 20 mg/l.

To compute DOC at time (t) for a 21-foot deep reservoir using Figure 3.4-3, we would divide the value at f(t) by 3 (i.e., 21'/7') and add the dilution water DOC concentration.

For example, using the low bookend curve for day 200 in Figure 3.4-3, the predicted DOC is 18 mg/l for a 7-foot deep reservoir. Diluting this value by 3 gives an estimated DOC of 6 mg/l in a 21-foot deep reservoir. When the diverted river water DOC concentration, which can range from 4 to 6 mg/l, is added to the computation, the predicted reservoir water DOC can be 10 to 12 mg/l.

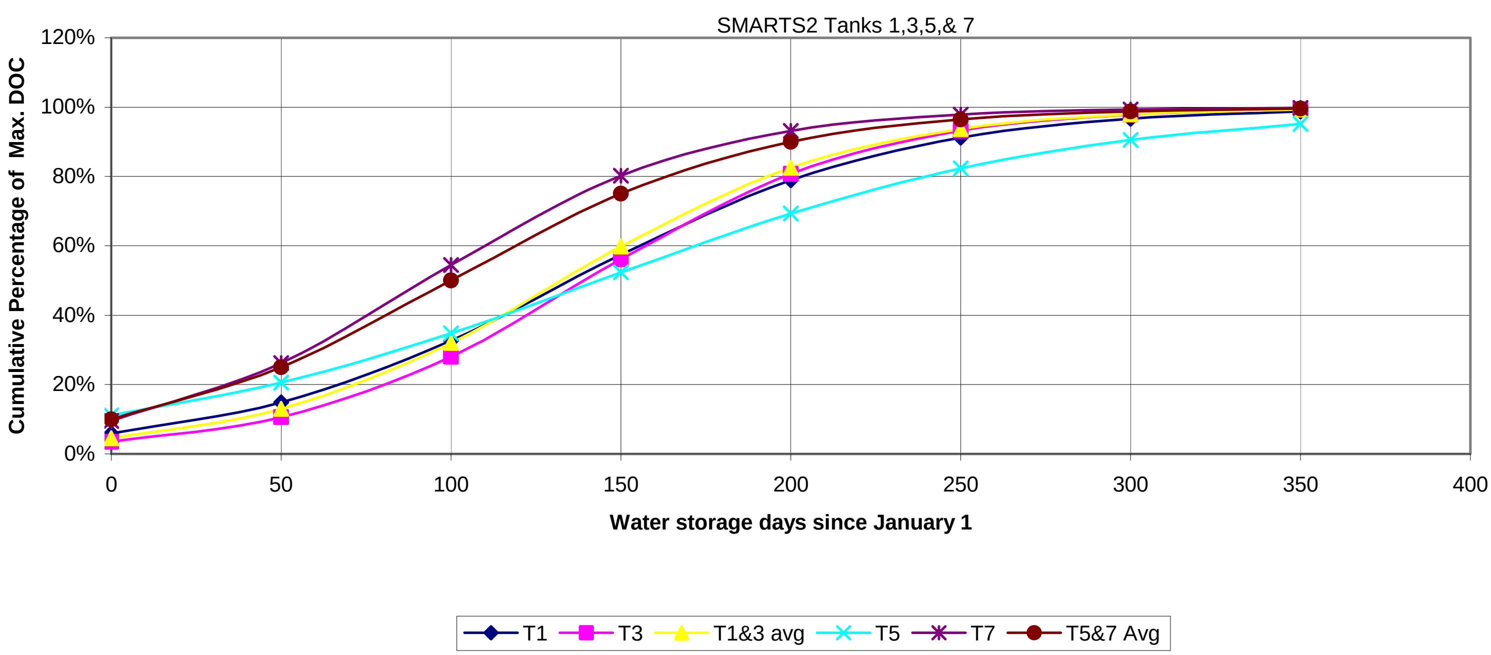
A simplified equation that incorporates the logistics equations, dilution factors, and diverted river DOC concentrations can be expressed as:

$$\mathbf{DOC(t) = DOC(0) + F(t)/Df}$$

where DOC (0) is the diverted river DOC in mg/l at filling, F(t) is the high or low bookend logistics equation, and Df is the appropriate dilution factor. The high bookend dilution factor is the reservoir depth (ft.) divided by 2. The low bookend dilution factor is the reservoir depth (ft.) divided by 7.

A plot (Figure 3.4-4) of the cumulative percentage of the maximum DOC concentration versus time showed that, in spite of different maximum DOC concentrations that observed in the tanks, the rates of DOC accumulation were similar. The data indicated that 50 to 80 percent of the maximum DOC levels could be reached in about 150 days and over 90 percent after 10 months of storage when the reservoir is filled in January.

Figure 3.4-4. Cumulative Percentage of Maximum DOC in Stored Water



Growth constants (k) are affected by water temperature, which in turn are affected by season. K values were also computed for each potential calendar month when water might be diverted to fill or top-off the reservoirs. Data from SMARTS Experiment #1 were examined to determine summer k values. The proposed k constants shown in Table

3.4-2 are based on observed water temperatures and the logistics equations of the two experiments.

Table 3.4-2. Model K Values Based on Reservoir Filling Periods
K growth rate constant units in per day

Reservoir Filling Period	Water temperature range	Low bookend k	High bookend k
November – March	7 – 12 °C	0.022	0.022
June – October	20 – 28 °C	0.042	0.070

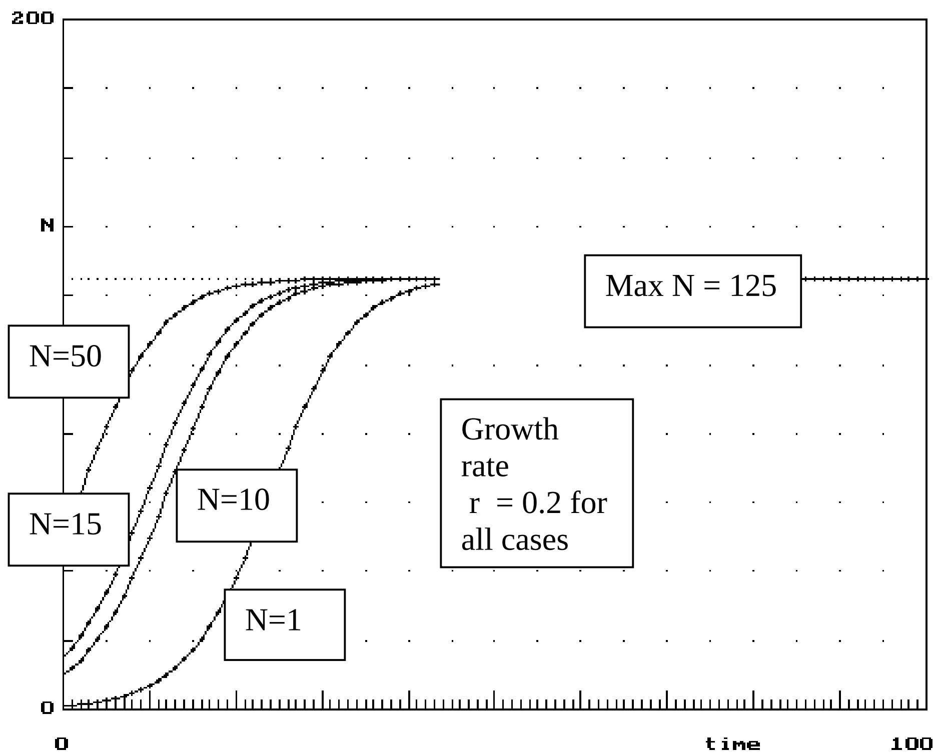
The summer k values appear to be reasonable estimates. The decomposition rate of organic carbon can increase by 2 to 4 times when temperature increases by 10°C within the tolerance limits of the organism (Reddy et. Al., 1980). This factor is called the Q10 value. Experiment #2 water temperatures were 7°to 12°C in November through March. Experiment #1 water temperatures (July to mid-October) were 20° – 28°C. The summer k values (0.04 – 0.07) were 2 – 4 times higher than the winter k values (0.02).

The DSM2 model will predict the diverted river DOC concentrations at the times of filling and compute the reservoir DOC concentrations using the logistics equations in Table 3.4-1 and the appropriate k values in Table 3.4-2. In the few cases of reservoir filling in June – October, the low and high bookend k values will replace the k values of the November – March low and high bookend logistics equations, respectively. The simulations will represent a 16-year hydrology (1975-1991) and variations in operating the reservoirs.

The effects of varying three factors: initial starting value, growth rate, and maximum value are illustrated in the following examples (Figures 3.4.6 to 3.4-8). The illustrations show that given time, the maximum values will be reached regardless of low growth rates or low initial starting values. In the case of a typical proposed reservoir island operation, water will be stored for 5-6 months prior to release. Under some conditions, water may be left on the islands for longer periods prior to discharge, thereby, increasing the opportunity to reach the maximum DOC levels. The maximum DOC levels were reached after 300 days in the SMARTS Experiment #2 tanks 1,3, and 7 and about 90 percent of the maximum DOC in tank 5.

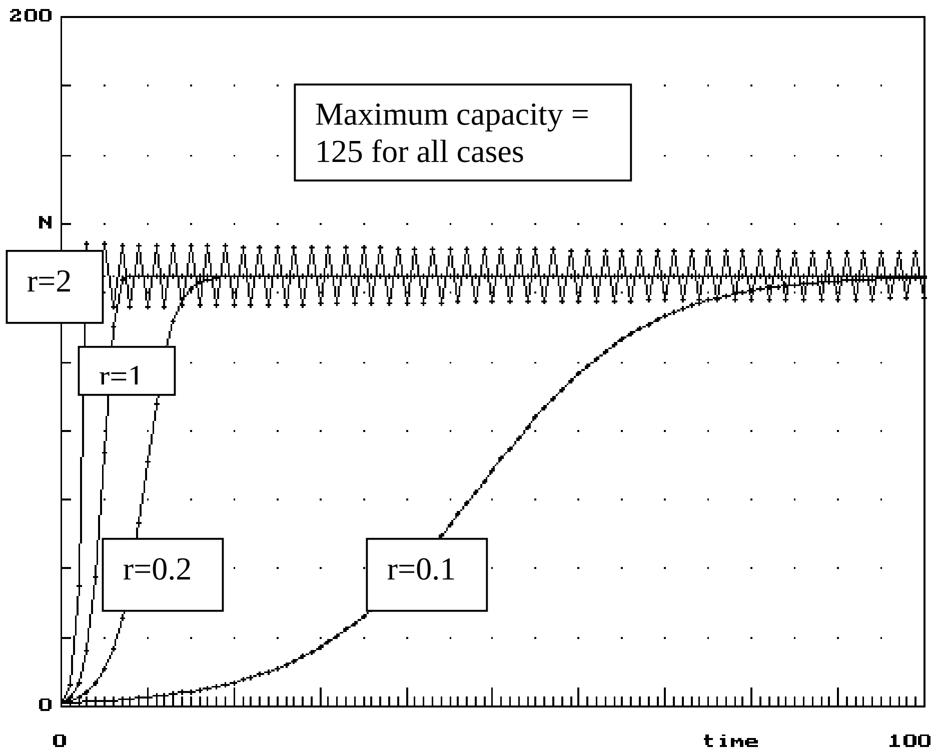
The two bookend logistics equations in Table 3.4-1 predicted DOC concentrations in the filled reservoirs at the time of summer discharge (150 holding days) were 5 and 12 mg/l DOC based on an initial source water DOC of 1 mg/l. Delta water diverted into the islands during the winter, however, can be up to 9 mg/l (e.g., Old River at Bacon Island, Station 09 at Old River, DMC intake) due to high runoff. This would result in much higher reservoir DOC concentrations.

Figure 3.4-5. Effect of Varying Initial Starting Values on Reaching Maximum Level



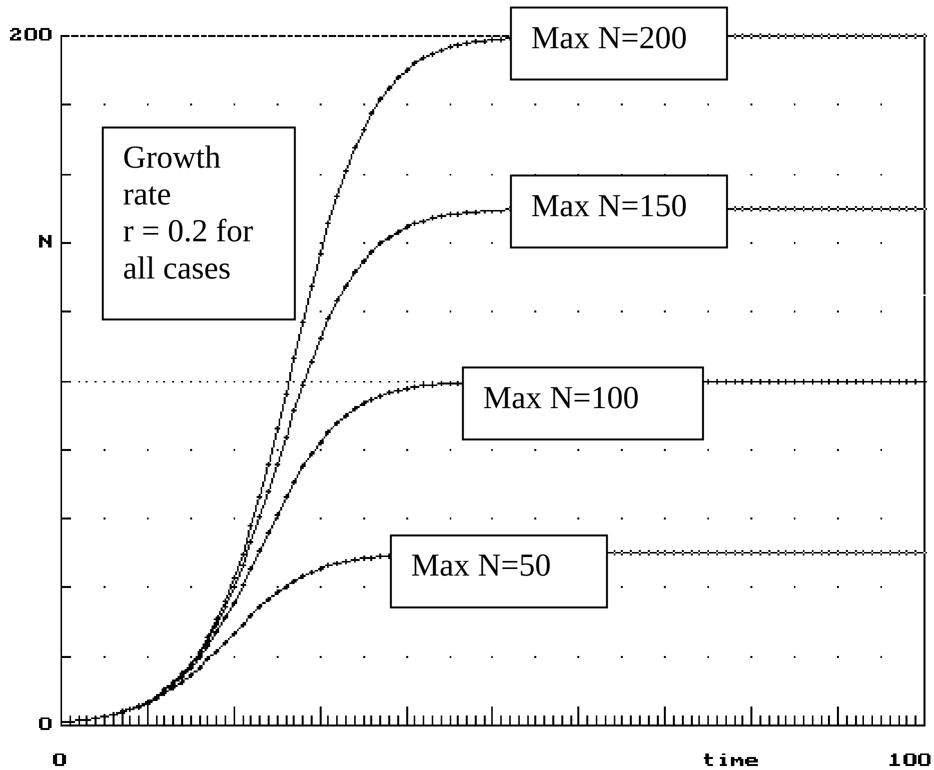
The above illustration shows that when the growth rate is held constant the maximum capacity (Max N) is reached sooner (time) with higher initial starting values (N) below the maximum capacity value. In this example, the growth rate, r, was held at 0.2, the maximum capacity set at 125, and initial values (N) at 1, 10, 15, and 50 units.

Figure 3.4-6. Effect of Varying Growth Rate on Reaching Maximum Level



This illustration shows how rapidly the maximum capacity (Max N) is reached when the growth rate is increased. The initial value is 1 in all cases. The maximum capacity is held constant at N=125 while the growth values, r, are increased from 0.1 to 2.0. At the fast growth rate of 2.0, the dynamics of the system bifurcate about the maximum capacity value (chaos behavior).

Figure 3.4-7. Effect of Varying Maximum Level Reached



This illustration shows the effect of different maximum capacity values for the same growth rate and initial value. Maximum capacity values of 50, 100, 150 and 200 are shown with the growth rate of 0.2 and initial value of 1 at start.

Seepage Return

The Seepage Return component addresses the DOC of seepage water that is returned back to the reservoir island by pumps located along the levees on some sides of the reservoir islands. A system of large extraction wells installed on the levees has been proposed by DWP owners to protect the adjacent islands from the anticipated effects of seepage from the reservoir islands. Seepage is expected because of the hydraulic pressure exerted by the stored water (average depth 20 ft.) over a deep sand aquifer that underlies the reservoir and extends to adjacent islands. The complex well system places pumps 160 ft. apart on the levees. A seepage analysis model (plan view) was used to consider seepage conditions within the sand aquifer. The model did not consider the influence of surface water infiltration from the proposed reservoirs or existing sloughs (URSGWC, 2000). The DWP geotechnical consultants recommended that the interceptor wells extend to the bottom of the sand aquifer on Webb Tract and Bacon Island.

Because reservoir projects on peat islands do not exist, there is no data on seepage water DOC. However, the Delta Wetlands Revised Draft EIR/EIS (Jones and Stokes, 2000) stated that "…a 9-month storage period with an assumed DOC concentration of 20 mg/l in the pumped seepage water results in an increased DOC loading estimate of 3 to 19 $g/m^2/yr$. This loading rate is relatively high compared to estimates of DOC loading under existing agricultural practices, which include a considerable amount of drainage to balance seepage from adjacent channels and maintain acceptable water levels for crop production".

The impact of returning seepage water with an assumed 20 mg/l DOC concentration, as described by the Delta Wetlands revised EIR, could add about 1 mg/l DOC to reservoir DOC concentrations. This concentration of DOC would be additive to that resulting from peat soil and biological organic carbon loads. Due to the lack of data from similar reservoir projects on peat soil. There is a high degree of uncertainty in predicting the increase of DOC from the planned return of seepage water back on to the proposed reservoir islands. However, the potential water quality impacts of the seepage return water may be significant and must be included in the assessment of the water quality-related risk and reliability of the project, its yield, and its ability to operate under the terms of the Water Quality Management Plan.

Plants and Algal Sources

The Plants component addresses the amount of organic carbon provided by aquatic plants and algae inside the reservoir. Within a natural open water body, organic carbon can enter from primary production of algae and plants and autotrophic production by photosynthetic and chemosynthetic bacteria. Sedimentation of algae and detritus will deposit organic matter at the bottom of the lake or reservoir, where it undergoes aerobic decomposition by macroscopic organisms, bacteria, and fungi.

Ecological Research Associates is serving as consultants to the development of this component. Their tasks are to:

1. Identify key parameters affecting plant growth and degradation on the islands.
2. Develop tractable groupings of plants that can be related to conditions on the islands and develop algorithms to describe plant growth.
3. Analyze fate of organic carbon fixed on the islands during plant growth and develop algorithms to describe degradation and release of organic carbon to the Delta channels.
4. Examine carryover affects from fill to fill and develop method of accounting for this in the modeling.
5. Transmit a report with the algorithms to the In-Delta Storage Water Quality Evaluation group, which discusses the study findings including caveats and limitations.

4. CONCLUSIONS

1. Initial DOC concentrations provided in the DWP Revised EIR/EIS were 6, 15, and 30 mg/l. The logistics equations that were developed from the SMARTS tank experiments predicted low and high reservoir water DOC concentrations at about 10 and 20 mg/l, respectively, during the summer water releases. The equations were used to predict the bookend values in the DSM2 water quality runs. The DSM2 model provides predictions over different hydrologic conditions and identifies how well the DWP releases can meet the constraints of the Water Quality Management Plan.

2. Under the DWP winter filling schedule, about half to 80 percent of the maximum DOC concentration would be reached in about 150 days and over 90 percent after 10 months of storage.

3. Predicted DOC from this peat soil organic carbon algorithm must be considered as the minimum predicted DOC concentration in the reservoir. Contributions from seepage return water and biological productivity over time are not included in this algorithm.

4. DWP consultants predicted DOC loads in seepage return water to be greater than from existing agricultural practices. Under this assumption, increases of reservoir DOC will occur from seepage returns. However, the amount of increase is difficult to predict as there are no similar type projects for comparison. If seepage DOC are as high as in drain water DOC or in the experimental tank pore water, the reliability of reservoir DOC at the time of release in meeting water yield and the Water Quality Management Plan will be at high risk.

5. The SMARTS studies did not simulate other potential operating schemes of the reservoir islands, such as dry periods between full discharge and filling or long-term storage beyond a year or seasonal shallow wetlands. The impacts from several years of continuous and interrupted use were also not explored or could be predicted from the work to postulate changes in subsequent DOC releases from the island soils. This further limits an adequate assessment of any consistency in providing long-term reliability and dependability of the water yield and in meeting the Water Quality Management Plan restrictions that were established for drinking water protection.

5. RECOMMENDATIONS

The differences between the magnitude of water quality changes seen in the SMARTS experiments and a reservoir Delta island would be expected from variations in the soil, water depths, and carbon production by plants and algae. The significance of wetland plants and phytoplankton in the reservoir islands as organic carbon sources has not been adequately addressed for water quality modeling purposes.

The major organic carbon source during the winter filling months will be from peat soil leaching and decay. As water temperatures and available sunlight increase, organic carbon production from photosynthetic plants and algae become new sources. Long-term experiments are needed to develop mathematical relationships for this component of the model.

There are no data to determine if groundwater returned to the reservoir islands by the many proposed seepage wells placed along the levees of Bacon Island and Webb Tract could degrade the water quality of the stored water. TOC concentrations of domestic wells were low (1 mg/l), but seepage water quality under the proposed reservoir conditions (21 ft. water depth and hydraulic head pressure) may result in higher organic carbon concentrations over time.

The SMARTS experiments provided logistics curves for modeling DOC from peat soil release and microbial decay. The logistic equations can provide rough estimates of the maximum DOC concentration in the reservoir water that is reached during storage. Different curves resulted from different maximum DOC concentrations of each tank which, in part, could be attributed to different soil conditions (e.g. organic carbon quality and quantities, C:N ratios, soil enzymes, nutrients) at startup or environmental conditions within the tank that affected microbial activity (e.g., growth, species, metabolism).

Currently, data to develop these equations are severely limited without any replication to quantify variability. More experiments could provide logistics equations for each soil type and condition of the islands. However, such experiments are time consuming and expensive. Other methods need to be explored to relate the potential of different types of organic soil in releasing organic carbon under flooded conditions and operations of the DWP.

The effects of wet and dry cycles on DOC availability in subsequent inundations have not been studied. Such experiments are needed to assess repeated filling and emptying of the project.

Other studies should examine methods that might reduce organic carbon releases from flooded peat soil. These methods might include tilling of fields in the summer to increase microbial breakdown of organic matter and draining the fields prior to filling. Some of these studies can be performed at DWR's SMARTS facility and laboratory.

The following studies that pertain to organic carbon from peat soil are recommended for next year:

1. Develop new test methods. Laboratory methods to rapidly correlate soil type and characteristics with organic carbon release need to be developed. SMARTS type experiments are expensive and time consuming to test all soils.

2. Update island soil survey. There is inadequate information on the distribution and character of soils with respect to organic carbon availability under flooded conditions on the islands. Organic carbon availability and release are associated with the flooded soil type. Soils vary within and among the DWP islands and soil maps are outdated. Testing other soils representative of the islands should be made to determine other possible logistics equations.

3. Experiments to reduce soil organic carbon. The effects of tilling or not tilling the fields prior to flooding on organic carbon as well as other possible management schemes should be studied.

4. Mimic wet-dry cycles on reservoir islands. It is not known if the effects of alternating wet and dry periods on the islands would increase or decrease soil organic carbon microbial processes (aerobic and anaerobic).

5. Integrate all components of DOC model in DSM2. Develop a more complete simulation of DOC impacts by incorporating organic carbon from seepage return flow and biological productivity with the existing peat soil model.

6. Integrate WQMP rules and restrictions into CALSIM operations model runs. The DWP yield and flexibility of the reservoir islands in meeting the WQMP and other Delta conditions must be fully assessed.

REFERENCES

Coughlin, R.F. and D.E. Zitarelli. 1989. Calculus with Applications. Saunders College Publishing.

Department of Water Resources. 1994. Five-year Report of the Municipal Water Quality Investigations Program, Summary and Findings During Five Dry Years, January 1987 – December 1991. November 1994.

Fiar, G.M., J.C. Geyer, and D.A. Okun. 1958. Water and Wastewater Engineering. Volume 1. Water Supply and Wastewater Removal. John Wiley & Sons, New York.

D'Angelo, E.M. and K.R. Reddy. 1994. Diagenesis of Organic Matter in a Wetland Receiving Hypereutrophic Lake Water: I. Distribution of Dissolved Nutrients in the Soil and Water Column. J. Environ. Qual., 23:928-936.

Forkel, D. 2001. Email from David Forkel of Delta Wetlands to Paul Hutton, Department of Water Resources, on seepage interceptor wells. 3/9/2001.

Gartley, Karen L. 2001. Chapter 10. Recommended Soluble Salts Tests. http://bluehen.as.udel.edu/deces/prod_agric/cp10-95.htm.

Hopkinson, Jr., C.S., A. E. Giblin, R.H. Garritt, J. Tucker, and M.A.J. Hullar. 1998. Influence of the benthos on growth of planktonic estuarine bacteria. Aquatic Microbial Ecology 16:109-118. November 1998.

Jones and Stokes Associates, Inc. 1990. Draft environmental impact report (EIR) and draft environmental impact statement (EIS) Delta Wetlands Project. December 1990.

Jones and Stokes Associates, Inc. 1993a. Final report: Water quality experiments on potential sources of dissolved organics and THM precursors for the Delta Wetlands Project. January 20, 1993.

Jones and Stokes Associates, Inc. 1993b. Draft environmental impact report (EIR) and draft environmental impact statement (EIS) Delta Wetlands Project. September 1993.

Jung, M. 2000. Revision of Representative Delta Island Return Flow Quality for DSM2 and DICU Model Runs. Prepared for the CALFED Ad-Hoc Workgroup to simulate historical water quality conditions in the Delta. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#3. December 2000.

Jung, M. and L. Weisser. 1999. A trial experiment on studying short-term water quality changes in flooded peat soil environments. Report for California Urban Water Agencies and Municipal Water Quality Investigations Program of the Department of Water Resources. Marvin Jung & Associates, Inc., Sacramento, CA. July 1999.

Jung, M. and L. Weisser. 2000. Final report on experiment #2: Seasonal water quality changes in flooded peat soil environments due to peat soil, water depth, and water exchange rate. Study conducted and funded by the Municipal Water Quality Investigations Program Division of Planning and Local Assistance California Department of Water Resources. Marvin Jung and Associates, Inc., Sacramento, CA. December 2000.

Jung, M. and Q. Tran. 1998. Delta Island Drainage Volume Estimates, 1954-55 versus 1995-1996. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#1. Marvin Jung & Associates, Inc., Sacramento, CA. January 1998.

Jung, M. and Q. Tran. 1999. Candidate Regions for Treatment to Reduce Organic Carbon Loads. Consultant's Report to the Department of Water Resources Municipal Water Quality Investigations Program, MWQI-CR#2. Marvin Jung & Associates, Inc., Sacramento, CA. January 1999.

Lial, M.L., C.D. Miller, and R.N. Greenwell. 1993. Calculus with Applications, Brief Version. Fifth Edition. Harper Collins College Publishers.

Madigan, Marinko, and Parker. 1999. Brock Biology of Microorganisms. Eight edition. http://cw.prenhall.com/bookbind/pubbooks/brock

Megonigal, J.P., S.P. Faulkner, and W.H. Patrick. 1996. The microbial activity season in southeastern hydric soils. Soil Sci. Am. J. 60:1263-1266.

Neter, J., Wasserman, W., and M.H. Kutner. 1985. Applied linear statistical models: Regression, analysis of variance, and experimental designs. Homewood, IL: Irwin.

Reddy, K.R., R.Khaleel, and M.R. Overcash. 1980. Carbon transformation in the land areas receiving organic wastes in relation to nonpoint source pollution: A conceptual model. J. Environ. Qual. 9:434-442.

Statsoft, Inc. 2000. STATISTICA for Windows, release 5.5. Tulsa, OK.

Todar, K. 1997. The effect of temperature on growth. University of Wisconsin-Madison. Edited version of 9/30/97. http://www.bact.wisc.edu/Bact303/NutritionGrow/temperature.html.

URS Grenier Woodward Clyde. 2000. Levee stability and seepage analysis report for the Delta Wetlands Project Revised EIR/EIS. Supplemental geotechnical report. May 22, 2000.

U.S. Geological Survey. 1995. Everglades water chemistry – DOC and other parameters. http://sofia.usgs.gov/metadata/sflwww/gachmdoc.html

U.S. Geological Survey. 1998. Dissolved organic carbon concentrations and compositions, and trihalomethane formation potentials in waters from agricultural peat soils, Sacramento-San Joaquin Delta, California: implications for drinking-water quality. Water Resources Investigations Report 98-4147.